Using a Mathematical Model To Assess the Hydrological Effects of Land-Use Change

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Summary

The objective of the study was to critically analyze the performance of a mathematical model of the hydrologic cycle with emphasis on its practical uses. The Hydrograph Laboratory Model (USDAHL) developed by the Hydrograph Laboratory, Agricultural Research Service, was used to study a watershed at the North Appalachian Experimental Watershed Research Center, Coshocton, Ohio. The Model's accuracy in simulating annual flows was evaluated, and the conclusion was reached that further improvement of the Model performance was limited by the accuracy of the rainfall data and by the ability to calculate evapotranspiration.

Model performance was compared with that of a regression equation, which gave a more accurate prediction of annual flow but required more data. The mathematical Model was sufficiently accurate, however, to establish the statistical significance of the hydrologic changes caused by reforestation and a thinning operation. Behavior of the study watershed was also modeled for a complete cover of hardwood forest, pines, and grass.

Land-use options for the study watershed were compared under a range of climatic conditions. The mathematical Model was used in a statistical experiment to analyze the variance in response to differing land-use policies. Significant differences were found between some of the options. Suppression of increased streamflow following clearcutting of a hardwood forest was found under dry post-treatment conditions. Comparison of policies in this way allowed a more rational evaluation of alternatives.

Introduction

The hydrologic effects of land-use change are of considerable interest to the watershed manager. Mathematical models of the hydrologic cycle are a relatively new tool for studying hydrologic change. Although considerable effort has gone into developing models, less effort has gone into applying them to assess the effects of land-use change. At this stage of model development, a critical examination of models is appropriate for evaluating practical management options.

The Tennessee Valley Authority (20)[3] developed a model and used it to study a forest operation. All marketable timber was removed from a small watershed followed by burning and planting of loblolly pine (*Pinus taeda*). Before treatment, 5 years of rainfall and streamflow data were available. The model calibrated on the first 3 years of data predicted satisfactorily the observed flows for the next 2 years. After treatment, predicted flows were too low, which indicated that the treatment had increased streamflow. After the magnitude of the change was checked, it was found compatible with other experimental evidence. The authors were impressed with the model's ability to respond to the variability of rainfall, particularly after treatment.

Fogel and others (6) combined a probabilistic rainfall model and the Soil Conservation Service method for relating rainfall to runoff. With these procedures, they predicted the hydrologic effect of urbanization of a desert shrub watershed in Ari-

[1]Cooperative research between the North Appalachian Experimental Watershed, North Central Region, Agricultural Research Service, U.S. Department of Agriculture, Coschocton, Ohio (in cooperation with the Ohio Agricultural Research and Development Center, Wooster) and the U.S. Dept. Agr. Hydrograph Laboratory, Plant Physiology Institute, Agr. Res. Serv., Beltsville, Md.

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[3]Numbers in parentheses refer to Literature Cited, page 23.

zona. Their procedure can be used on ungaged watersheds although the authors do point out several limitations.

Hendricks and Ligon (*14*) described the use of a mathematical model in an attempt to detect the hydrologic effect of urban development. A self-calibrating version of the Stanford Watershed Model was used on a watershed under increasing urban development. A similar watershed in the original rural condition was used as a basis of comparison. The parameters of the model calculated for each watershed were compared to see if significant differences could be found, for example, in infiltration. The authors concluded that the model was not sensitive enough to detect the effects of urbanization.

Although the detection of such changes can be based on a comparison of computed with observed streamflows or on model parameters, the significance of the changes should be based on the magnitude and the dispersion of the errors in the calculated flows or parameters. Errors are easier to evaluate in calculated streamflow than in the parameters describing a particular process. Parameters gained from an optimization of streamflow may produce a correct water balance, but individual elements within the balance may be of the wrong magnitude.

No way of checking the individual components of a model is possible unless sufficient experimental data are available. For example, England and Coates (*5*) modeled the behavior of a weighing lysimeter where evapotranspiration and percolation could be checked against measured values. Uncertainties in checking the individual components of a model make it difficult to evaluate the causes of hydrologic change.

In studies by Glymph and Holtan (*7*) and Glymph, Holtan, and England (*8*), the USDA Hydrograph Laboratory (USDAHL) Model (*17*) was used to assess the hydrologic response of watersheds to land-use management. Three levels of land management were considered: exploitive, conservative, and complete grass cover for three watersheds located at Coshocton, Ohio, Hastings, Nebr., and Riesel, Tex., respectively. The annual streamflows for each watershed at each level of land management were compared. For example, at Hastings the annual streamflow would be increased by 6.4 inches if the exploitive management was adopted. Reductions of 11.7 and 17.8 inches would result from conversion to conservative and grassland management. The authors were careful to stress that although the figures were of the right order and in the right direction, they were not precise.

Two of the principal benefits of modeling are the gathering together of all the hydrologic information in a logical manner and the stimulation to think about old problems in new ways. The strongest point of the available models was the description of the effects of differing rainfall patterns.

A decision was made to concentrate on variations in the effects of land-use change under a range of rainfall conditions. Comparison of several land management options under a range of different rainfall conditions would be of practical value in selecting the most viable management policy. For conducting such comparisons, the USDAHL Model (*17, 18*) was adopted because it was specifically developed to study land-use change. For our purpose, emphasis should be placed on the use and performance of the Model rather than on further development. The major study objectives were as follows:

(a) To assess Model accuracy for hydrologic simulation and the ultimate level of Model accuracy, given the quality and extent of current hydrologic data;

(b) To compare the Model simulation accuracy with equivalent statistical methods;

(c) To assess the Model's ability to detect hydrologic change;

(d) To assess the use of the Model when assigning causes for hydrologic change; and

(e) To develop a technique for comparing land-management options under varying rainfall conditions or, more specifically, to use the Model to investigate whether a given management option has the same effect on streamflow under different antecedent and post-treatment rainfall conditions.

Selection of a Watershed for Study

A long hydrologically stable record is necessary to evaluate the accuracy of the Model. Hydrologic change is also necessary if the Model is to be used for detection purposes. Relatively severe land-use changes were considered desirable. If the effect of such changes could not be detected, then more refinements of the Model would be required. An added benefit would be well-documented statistical studies on the hydrology of the watershed.

A 43.6-acre watershed at the USDA North Appalachian Experimental Watershed Research Center, Watershed 172 (*11*), satisfied the requirements

for a study watershed. The watershed is located at 40° 22′ N and 81° 48′ W, about 10 miles[4] northeast of Coshocton, Ohio.

The area is typical of much of the unglaciated Allegheny Plateau—bedrock is sedimentary, mostly sandstone and shale with some clay, limestone and coal. Soils are residual Muskingum-Keene with silt loam texture, crumb structure, moderate permeability, and medium internal drainage. Average landslope is 23 percent with a southerly aspect and has good surface drainage.

Hill[5] described the early history of Watershed 172. Farming began in the 19th century, but in the early 20th century, severe erosion had greatly reduced crop productivity and the land was given over to pasture of poor quality. Broomsedge (*Andropogon virginicus*), poverty oatgrass (*Danthonia spicata*), and staghorn sumac (*Rhus typhina*) were the principal vegetation types.

In 1938 reforestation started in the open areas of Watershed 172. Initially three small areas (about 2 acres) of black locust (*Robinia pseudoacacia*) were planted, and in the spring of 1939 the remaining open area was planted to eastern white (*Pinus strobus*), pitch (*P. rigida*), Virginia (*P. virginiana*), and Scotch pines (*P. sylvestris*). Three major vegetation types were grown on the 43.6 acre watershed: 12.8 acres of residual hardwoods, 28.9 acres of assorted pines, and 1.9 acres of black locust. By 1949 a dense cover of vegetation had become established.

No formal management of the forest existed except for the removal of a tenth acre per year of black locust for fence posts. Hardwood species, particularly elm (*Ulmus*) and black cherry (*Prunus serotina*), invaded the area along the stream channel and roads. In the winter of 1967-68, some thinning operations were carried out, followed in the next year by more thinning and a clearcut in an area next to the stream. In the summer of 1970, another small area of hardwood was cut. There were two distinct land-use changes to be studied: reforestation with a consequent decrease in streamflow and a thinning operation leading to a possible increase in streamflow.

Recording of rainfall and streamflow started in 1938, and by 1940 temperature and pan evaporation were being measured. These measurements were sufficient for use of the USDAHL Model. In 1972 measurement ceased, leaving 32 years of high quality data for study. The weir was shifted a short distance downstream in 1966. Any subsequent streamflow changes might reflect either this shift or the thinning.

Table 1.—*Streamflow reductions between 1939-67*

Period	Streamflow reduction 1939-67	Significance level
	Inches	*Percent*
Growing season	2.77	0.1
Dormant season	4.45	.1
Water year	7.19	.1

The observed reduction in streamflow following reforestation has been the subject of three statistical studies: Harrold and others (*11*) gave a detailed description of four watersheds at Coshocton and statistical analyses of the effects of changing land-use on streamflow. Simmons[6] repeated the statistical analysis using an extra 10 years record from 1958 to 1967. The decreases in streamflow for the growing season, dormant season, and water year are found in table 1.

Mustonen and McGuinness (27) used measured evapotranspiration from a lysimeter under a crop of deep-rooted bromegrass and alfalfa as a basis for comparison with watershed evapotranspiration obtained by water balance calculations.

Some general conclusions may be drawn from these three statistical studies:

(a) The climate for 1938-67 represented the long-term climate of the region based on rainfall records for Coshocton;

(b) Annual streamflows showed significant decline during 32 years, amounting to 7.2 inches over a water year; most of the decline occurred between 1939 and 1950;

(c) The trend in streamflow after 1950 was negligible indicating that the effects of reforestation had stabilized;

(d) Except for extreme floods, flow decreases were detected over the whole range of flows from high to low;

(e) Ground water levels at the end of the growing season showed significant declines whereas those at the end of the dormant season did not; and

(f) Comparison of watershed and lysimeter evapotranspiration showed that evapotranspiration from Watershed 172 increased 30 percent between 1938-39 and 1950-51.

[4]See appendix A for factors to convert English units of measure to metric.

[5]L. W. Hill. Influence of the establishment and development of a plantation upon some precipitation and runoff relationships on a small watershed in southeastern Ohio. Unpublished Master of Forestry Thesis, Univ. of Michigan, 145 pp. 1959.

[6]P. W. Simmons. The influence of land use and treatment on the hydrology of small watersheds at Coshocton, Ohio, 1938-1967. Unpublished Master of Science Thesis, Dept. of Civ. Engin., The Ohio State Univ., 149 pp. 1968.

Harrold and others (*11*) concluded that reforestation had produced a dense vegetation canopy, which increased the interception of rainfall. Litter produced by the forest increased infiltration capacity so that less water ran directly over the surface and into the stream. Percolation had been reduced by increased interception and transpiration of water from the forest canopy compared to the poor quality pasture that existed previously. During the growing season, the lower percolation reduced the ground water levels. In the subsequent dormant season more of the available water was required to recharge ground water, which left less for streamflow.

Hydrograph Laboratory Model

The USDAHL Model of the hydrologic cycle developed by Holtan and Lopez (*17, 18*) was chosen for the study because it had been specifically designed to model land-use change. Mathematical equations describing each hydrologic process were used as the basis of a computer program. A flow chart of the program is shown in figure 1. When possible each hydrologic process was described by a subroutine, for example, evapotranspiration by ETCALC. Modifications to an equation can readily be made by modifying the subroutine rather than the whole program.

The Model, intended to solve practical problems involving land use and hydrology, was designed to process a wide range of climatic and watershed conditions. To fulfill this goal, the Model's program was written for the level of hydrologic data generally available; however, it must be modified to take advantage of situations where more comprehensive hydrologic data are available.

Although there can be much argument about the mathematical description of the hydrologic processes, there can be less about the philosophy behind the Model. It was aimed at wide application for the solution of practical problems with the underlying recognition that this development is an evolutionary process.

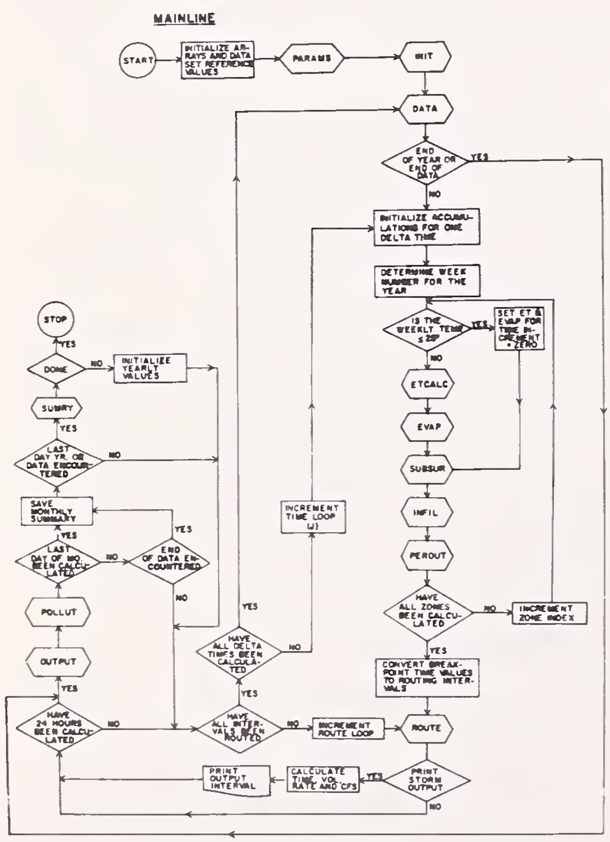

Figure 1.—Flowchart of the Hydrograph Laboratory Model.

Climatic Data

Three climatic variables are required as input to the Model: precipitation, air temperature, and pan evaporation. Full calendar years of data are required for computations with the Model.

Recording Rain Gage 103, located about 500 feet east of the watershed boundary (see fig. 19, p. 25), measured precipitation on Watershed 172. The precipitation data were in breakpoint form, that is, the time intervals were chosen so that the trace on the chart of the recording rain gage could be described with a minimum of points. The time intervals were of the order of minutes during heavy rain, increasing to daily and even weekly if no precipitation fell. Snow was labeled to separate it from rain. The snow measurements were based on the readings of the recording rain gage and visual observations of the snow.

Pan evaporation, computed on a year-round basis by the National Weather Service method (22), used climatic data from the central meteorological station located about one-third mile east of the watershed. Average weekly air temperatures were also calculated from measurements at that site.

Although monthly streamflow is used throughout this publication, all the calculations, including streamflow, were based on breakpoint time intervals determined from the precipitation record, and

no time intervals greater than 24 hours were used. In some instances the time interval used in routing the channel flows was shorter than the breakpoint interval of the rainfall.

Watershed Parameters

As many of the Model parameters as possible should be based on physical measurement to allow calculation of streamflow in areas where little or no data are available. The current generation of models has not reached this stage of development because at least one of the parameters must be obtained by fitting the calculated results to the observed data by an optimization procedure. For this study all the watershed parameters (as distinct from the crop parameters) were derived from physical measurements on the soils and topography and patterns of ground water flow from the watershed. A more detailed description of the basis for the watershed parameters may be found in appendix B.

Zoning

One of the distinctive features of the USDAHL Model is the division of a watershed into subareas or hydrologic response zones. Each zone is considered a homogenous unit in a hydrologic sense, and calculation of infiltration and evapotranspiration are averaged over a zone. Excess surface water from each zone is cascaded to the next zone or diverted either into the stream or onto the alluviums next to the stream. Subsurface flows from each zone layer may be diverted onto the alluviums or into the stream. All water diverted onto the alluviums contributes to infiltration or overland flow. Infiltrated water is again subject to evapotranspiration. In most situations the alluviums receive a larger amount of water for evapotranspiration and plant growth.

To set up the Model, a watershed is divided into zones and layers. Each zone must have the same number of layers. A convention of numbering the zones from the ridge (zone 1) to the alluviums around the stream was adopted up to a maximum of four zones. The basic aim of zoning is to divide a watershed into areas that are as homogeneous as possible. Soil characteristics and topography are of major importance. The division of Watershed 172 into four zones is shown in figure 19.

Soils

The USDAHL Model required that the soil profile be divided into two layers so that the total depth of soil was enough to include the deepest root systems. The top soil or upper layer was interpreted as the layer from which plants draw the majority of their moisture.

Infiltration and moisture-holding capacity are the two hydrologic properties of the soils described quantitatively. For example, infiltration is defined by

$$f = GI \; A \; S_a^{1.4} + f_c \qquad [1]$$

where

f = infiltration capacity in inches per hour
GI = growth index
A = basal area rating of the crop
S_a = available storage for infiltrated water in the surface layer of the soil
f_c = constant rate of infiltration after prolonged wetting.

The moisture deficit in the top soil, the percentage of cracks, and the final steady rate of infiltration of saturated soil are required to calculate infiltration rate. The moisture-holding properties of the soil are described by G, the percentage by volume of the soil freely drained by gravity flow between moisture contents of field capacity and saturation, and the available water capacity (AWC), the percentage by volume available to plants between moisture contents at wilting point (15 bars tension) and field capacity (0.3 bars tension).

Routing

Holtan and Lopez (17) described the method for obtaining routing parameters from recession curves plotted on semilogarithmic scales. In all, four routing parameters were used: m_c for the stream channel, m_1 for the first layer of soil, m_2 for the second layer of soil, and m_3 for the deeper ground water storage. The watershed parameters used throughout the study are shown in appendix B, table 21.

Crop Parameters

The forests in Watershed 172 were separated into pines and hardwoods for modeling purposes.

Two crop parameters modify infiltration as shown in equation 1. The *A* value is a measure of the surface connected porosity and takes a value between 0.0 and 1.0. The growth index, a measure of the stage of crop growth, also modifies infiltration. Depression storage is another surface parameter and was included with the crop parameters because it is modified by cultivation practice. Root depths were based on observations of rooting patterns on the sides of pits dug during the soil survey.

The other crop parameters, which control the amount and seasonal distribution of evapotranspi-

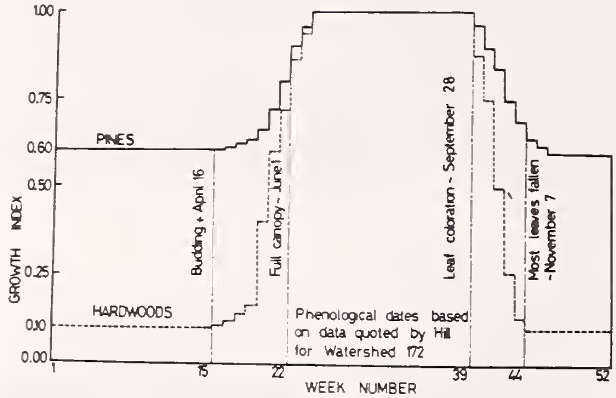

Figure 2.—Growth index curves for hordwoods ond pines.

ration, were difficult, if not impossible, to evaluate from existing data. Values for the ratio of evapotranspiration to pan evaporation (ETEP) and the growth index (GI) values for the dormant season were obtained by calibrating the Model using streamflow data from Watershed 172.

Equation 1 from Holtan and Lopez (*17*) shows that a plant factor or GI and a soil moisture depletion factor both serve to reduce actual evapotranspiration below the potential. Potential evapotranspiration is computed as the product of ETEP and pan evaporation. On the basis of numerous studies of free water evaporation, the ETEP ratio should be 0.7 to 0.8. The value of ETEP calculated from the calibration of the forested watershed streamflow was 1.2. Use of a value of ETEP of 0.7 would cause large errors in the modeled water balance.

The parameters ETEP and GI were considered numbers that produced a correct water balance for the particular crop; however, no attempt was made in this study to give them a physical significance. There is a need for more detailed research on the evapotranspiration of forested watersheds.

The GI curves were constructed from phenological information for Watershed 172 provided by Hill[7]. Figure 2 shows the average dates. The value of the growth index for hardwooods and pines was taken as 1.0 for the summer period, between June 1 and September 28. The winter growth indices from November 7 to April 16 were also constant, but the pines were assumed to have a higher growth index in winter because of their evergreen habit.

The values of the winter growth index were adjusted for hardwood and pine in the calibration process. The growth indices for spring and autumn were fixed by drawing a smooth curve from the winter growth index (ending at April 16) and the summer growth index (starting on June 1). The summer growth index was fixed at 1.0. The two final growth index curves obtained by calibration of the USDAHL Model against streamflow data from Watershed 172 are shown in figure 2. Table 2 shows the proportion of each zone covered by hardwood and pine. The crop parameters for pine and hardwood forest are shown in table 3.

Table 2.—*Proportion of forest types in each zone*

Zone	Hordwoods	Pines
	Percent	*Percent*
1	100	0
2	22	78
3	23	77
4	84	16

Crop parameters appropriate to a deep-rooted pasture of bromegrass (*Bromus inermis*) and alfalfa (*Medicago sativa*) were also required for the simulation of land-use change. A later version of the USDAHL Model was used for the simulation of the behavior of grass. The major difference was the calculation of seasonal values of growth index from an upper and lower temperature. Crop parameters for the pasture were obtained from calibration of the Model against measured values of evapotranspiration from a monolith lysimeter at the North Appalachian Experimental Watershed Research Center.

Modifications To the Hydrograph Laboratory Model

Canopy interception

Because the USDAHL Model had been designed for agricultural crops, canopy interception was included in evapotranspiration. Application of the Model to the forests of Watershed 172 made sepa-

Table 3.—*Crop parameters for hardwoods and pines*

Porameter	Hordwoods	Pines
A value	1.00	0.50
V_D ---inches[1]	.05	.05
ETEP	1.20	1.20
Rooting depth, ---inches	72.00	72.00
Interception copacity, ---inch	.03	.03
Evergreen	Folse	True

[1]Volume of depressions thot would store rainfoll until it infiltroted.

[7]See footnote 5, p. 3.

rate consideration of the canopy interception necessary. The terms used in the studies of interception have been defined by Helvey and Patric (*13*) who provide a review of experimental results for hardwoods of the Eastern United States.

Boughton (*1*) described a simple mathematical routine for interception consisting of a single storage corresponding to the interception capacity. Water in the storage was removed at the potential evaporation rate, and rainfall in excess of the storage deficit reached the ground as throughfall. This procedure was used as a basis for an interception sub-model for calculating net rainfall. The principal features of the sub-model are as follows:

(a) For the deciduous hardwoods, the interception capacity was multiplied by the growth index to introduce a seasonal component;
(b) For the pines, the interception capacity was fixed throughout the year;
(c) Evaporation from intercepted water was allowed to proceed during rainfall;
(d) Transpiration was stopped when water was present in interception storage;
(e) Evaporation rate was determined from pan evaporation (which is used as an estimate of potential evaporation in the USDAHL Model); and
(f) An interception capacity of .03-inch was used.

The performance of the interception subroutine was assessed as part of the model test.

Snowmelt

Harrold and others (*11*) stated that snowfall is not a major source of precipitation at the North Appalachian Experimental Watershed Research Center. The average winter produces about 19 inches of snow, and if the average water content of the snow was 10 percent, less than 2 inches of the 37.6 inches of average annual precipitation would be snow.

This small amount of snowfall, however, can produce major errors in modeling of particular events. For example, if the Model is erroneously given 1 inch of precipitation as rain falling on a saturated watershed in winter, most of the precipitation will run off immediately; however, if the precipitation was really snow, it would remain on the surface of the watershed and melt slowly as the temperature rose. A study by Wei (*36*) concluded that the incorporation of a subroutine describing snowmelt into the USDAHL Model would improve modeling of the hydrology of watersheds.

A simple model of snowmelt was used because of limited data. The precipitation falling as snow had been listed separately so that the snow could be placed in a separate storage in the model and melted according to weekly average temperature:

$$\text{Melt/day(inches)} = 0.005(T^\circ - 32) \text{ in a forest}$$
$$\text{Melt/day(inches)} = 0.005(T^\circ - 27) \text{ in an open field}$$

where

T° = average weekly temperature in °F.

Melt continues until the volume of water in the snow storage has been depleted.

Modeling the Hydrology of the Study Watershed

Calibration

Calibration of the Model was the first stage in the modeling of Watershed 172. Statistical studies described previously showed little trend in streamflow between 1950 and 1965. The 16 years were broken up into two 8-year periods to calibrate and test the Model. The first 8 years from 1950 to 1957 were selected to calibrate the Model because they covered a wider range of climatic conditions than did 1958 to 1965. Ideally, the test period should cover a similar range of conditions, but the Model must be tested against a measured sequence of streamflow. Such a completely representative sequence was not available.

Representativeness of the rainfall during the four climatic periods of the modeling study is shown in table 4. In the table, t is the value of Student's two-tail test of significance, and the probability is that the record for the period would be expected to occur in random sampling from the long term record (*11*). The 10 years from 1940 to 1949, when the streamflow was actively declining, was called the reforestation period and the 6 years between 1966 and 1971 the period of partial cutting.

The amount and seasonal distribution of evapotranspiration were varied to produce an optimum fit between the observed and predicted annual flows for the calibration between 1950 to 1957. The ratio of the potential to pan evaporation (ETEP) controlled the amount of evapotranspiration, and

Table 4.—*Representativeness of climatic periods*

Period	t	Probability
		Percent
1940-49 reforestation	0.35	75
1950-57 calibration	.16	90
1958-65 test	—1.32	20
1966-71 partial cutting	—1.75	10

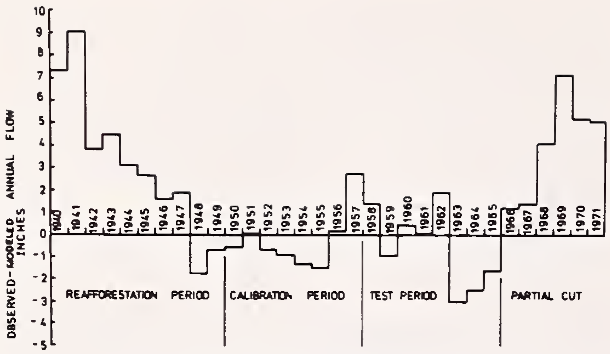

Figure 3.—Deviations (32 years) between observed and model simulated annual flows.

variation of the winter growth index influenced the seasonal distribution. The phenological dates outlined previously were fixed during the optimization process, as were all the other catchment and crop parameters. A direct-search optimization technique was used to minimize the sum of the obsolute values of the deviations between predicted and observed annual flows.

Model Simulation Accuracy

Figure 3 shows the differences between Model simulated and observed annual flows for the 32 years from 1940 to 1971. The parameters for mature forest, obtained from the Model optimization, were used over the entire 32 years. The standard deviation of the differences for the calibration period was 1.46 inches or 13 percent of the mean annual flow for the period and 1.76 inches or 22 percent of the mean for the test period.

A nonparametric test was applied to the differences between observed and Model simulated annual flows for the calibration and test period together. The rank correlation test used was developed by Kendall (*21*) and briefly described by Tintner (*34*). The coefficient of disarray was -0.13 compared with the 5 percent confidence limit of ± 0.37 indicating that there was not a significant trend in the differences. The calibration and test periods were also tested individually for trends: the test period did not show a significant trend; however, the calibration period did. The small magnitude of the trend in the calibration period means that it would not have an important effect on the conclusions of the study.

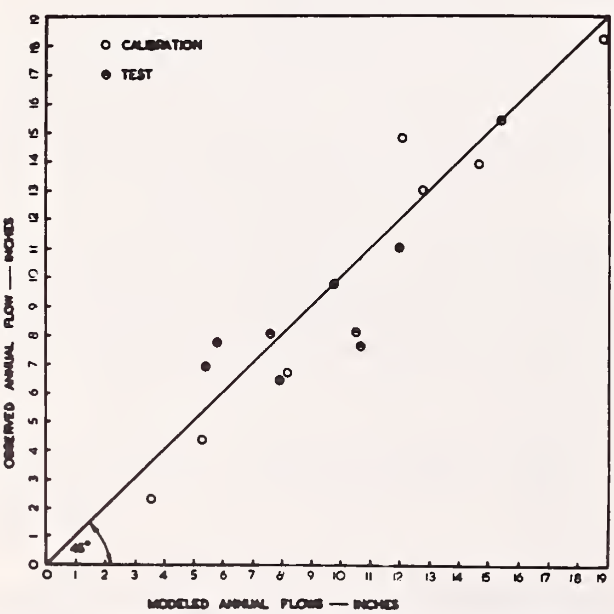

Figure 4.—Model simulated versus observed annual flows—calibration and test periods.

Figure 4 shows the Model simulated annual flows plotted versus observed flows for the calibration and test periods, and figure 5 shows the monthly hydrographs for the calibration and test periods.

The ultimate limit of accuracy for the Model simulated streamflow would be determined by the accuracy of the input data. A brief analysis of errors was undertaken to determine the level of accuracy which could be expected when given the data available.

Since infiltration was not a limiting factor for the forested Watershed 172, the long term average annual streamflow can be taken as the difference between precipitation and evapotranspiration (including interception). The errors in modeling of annual

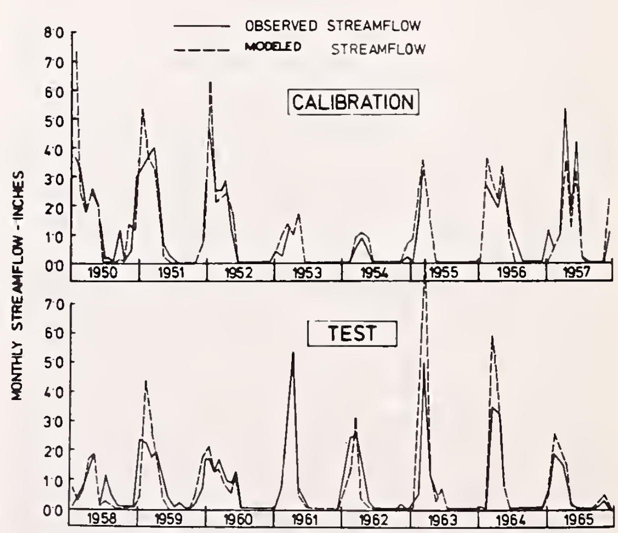

Figure 5.—Monthly hydrographs—calibration and test periods.

streamflow will result from errors in measuring rainfall and errors in calculating evapotranspiration from the meteorological data:

RO = model simulated annual streamflow
P = annual precipitation
E = annual evapotranspiration (including interception calculated from meteorological data)
δP = error in measuring precipitation
δE = error in calculating evapotranspiration

$$RO = (P \pm \delta P) - (E \pm \delta E)$$
$$= P - E \pm (\delta P + \delta E) \qquad [2]$$

An error of ±5 percent in the measurement of precipitation or calculation of evapotranspiration would probably underestimate the errors in most situations. The errors in Model simulated annual streamflow, which could result from 5 percent errors in rainfall and evapotranspiration, were compared with the actual errors in Model simulated streamflow for the calibration and test periods.

The average values of precipitation and evapotranspiration for Watershed 172, given by Mustonen and McGuinness (27) for the water years 1950-51 to 1964-65, were used to calculate the errors based on equation 2. The errors in Model simulated streamflow for the calibration and test periods are shown in table 5, together with expected errors calculated from equation 2. The limits of accuracy for the Model simulated streamflow were calculated on the basis of twice the standard deviation of the differences between observed and Model simulated annual flows.

The similarity between the errors calculated from equation 2 and the actual errors in Model simulation indicate that unless rainfall can be measured more precisely than ±5 percent or evapotranspiration calculated more precisely than ±5 percent, the Model simulation cannot be improved. Rainfall probably cannot be measured within these limits by the existing rain gage or evapotranspiration calculated more accurately using the data available. Further attempts at improving the Model simulation by using more sophisticated optimization techniques without a corresponding increase in accuracy of data would be meaningless.

Table 5.—*Errors in Model simulation (inches)*

	Average water year streamflow	Limits of accuracy
Calibration period:		
Based on ± 5 percent errors and equation 2	10.00	±3.4
Simulated	9.91	±2.9
Test period:		
Based on ± 5 percent errors and equation 2	9.60	±3.3
Simulated	9.33	±3.5

Comparison of Model Simulation with a Statistical Technique

Previous statistical analyses of the data from Watershed 172 (2, 11, 29) utilized Watershed 196 as a control. Since Watershed 196 was managed in the same way throughout the entire period, its annual streamflow reflects variations caused by climate alone. Thus, Watershed 196 streamflow is a suitable covariate to remove the effects of climate from the record of a treated watershed.

A multiple regression with annual streamflow on the control Watershed, Q196, and time in years from the middle of 1940-65, t, as the independent variates was used to predict reforested watershed annual streamflow, Q172. The resulting equation

$$Q172 = -0.05 + 0.79Q196 - 0.21t,$$

was used to predict Q172 streamflow. The standard error of the regression Model was 1.19 inches.

The USDAHL Model was also used to simulate streamflow from Watershed 172. The parameters determined during 1950-57 calibrations were used to predict flow for 1950-65 and after appropriate changes in the values for interception, rooting depth, A value, and evapotranspiration, during 1940-49 regrowth.

The standard error of the Model simulated flow deviations of 1.54 inches is about 30 percent greater than the regression standard error. This is a small price considering that the regression method required 26 years of data from each of the reforested and control watersheds. The Model required only 18 years of data from the reforested watershed (8-year calibration and 10-year reforestation) and could, in fact, have been successful with less of a calibration period.

The two sets of deviations are not related to each other; the correlation coefficient was only 0.188. This is not surprising because the predicted flows were derived by distinctly different methods. The correlation coefficient between the annual flows predicted by the two methods (not their deviations from observed flow) is 0.919, which is highly significant statistically. Thus the two methods predicted essentially similar flows throughout the record period.

Detection of Hydrologic Change

Figure 3 shows the deviations between observed and Model simulated annual flows. The crop parameters used in the modeling were based on the calibration period when the forest was in a mature state and when there were no trends in streamflow. The deviations in the reforestation period include changes in the hydrology as well as errors in modeling.

Large positive deviations between observed and Model simulated annual flows in the early part of the reforestation period indicate that the modeled flows were too low, and evapotranspiration or interception, or both, had been overestimated. In other words, the evapotranspiration or interception, or both, of the young pine seedlings was lower than for the older forest as existed during calibration. The deviations declined steadily as the pine forest grew, and by the latter part of the 1940's they were within the limits of accuracy defined by the test period.

Magnitude and decline of the deviation agreed with the results of the statistical study of Simmons.[8] The deviation in 1940 was 7.3 inches compared with 7.19 inches change in the annual flow quoted by Simmons. In addition, the statistical study indicated that by the late 1940's changes caused by the growing forest had stabilized, as also shown by the Model simulated flows.

The next stage was to determine whether changes predicted by the model were statistically significant. The deviations in the first 4 years of reforestation were greater than twice the standard deviation derived from the test period (2×1.76 inches $= 3.5$ inches) so that the change was significant at the 5 percent level.

Nonparametric tests avoid the assumption of normality of deviations and provide a sounder base for conclusions. The deviations from 1940 to 1965 made up of the reforestation, calibration, and test periods were examined to see if there was a significant trend. The coefficient of disarray for the 26 deviations was -0.47 compared with a 5 percent confidence limit of ± 0.29 indicating that there was a significant decline in the deviations. No significant trend was found for the calibration and test periods when taken as a continuous 16 years.

The Mann-Whitney Test as described by Guttman and Wilks (9) was applied to the deviations between observed and Model simulated annual flows for the 10-year reforestation and 8-year test period as a pooled sample. The random variable:

$$\frac{W - mn / 2}{\sqrt{mn\ (m + n + 1) / 12}}$$

where

$W =$ Monn-Whitney Stotistic

$m = 10$ i.e., the number of yeors in reforestation period, and

$n = 8$ i.e., the number of yeors of the test period,

had a value of -2.83 for the 18 deviations. Since this random variable approximates a normal distribution N(0, 1) the deviations in the reforestation period were significantly different from those in the test period.

The conclusion can be drawn from the three statistical tests on the deviations that the Model was sufficiently accurate to detect the changing hydrology and decline in streamflow brought about by reforestation. In addition the results obtained by Model simulation were in good agreement with the results of the previous statistical studies.

Figure 3 also shows the deviations between observed and Model simulated flows of partial cutting from 1966 to 1971. Large positive deviations were observed starting in 1968. The increases in flow from 1968 to 1971 were significant based on twice the standard deviation of the errors in the test period (i.e., 3.5 inches). The coefficient of disarray for the deviations for 1950 to 1971 (calibration, test, and partial cutting periods) was $+0.33$ compared with a 5 percent confidence limit of ± 0.31, indicating a significant upward trend in streamflow.

During the winter of 1966-67 there was a thinning operation in the pine forest followed by a more severe operation during the winters of 1968-69-70. The increase in flow may also have been caused by the construction of a new weir in 1966 just upstream from the old one. The Model was accuate enough to detect a significant increase in streamflow whatever the cause.

Modeling Interception

Interception is one of the few processes in the hydrological cycle where intermediate measurements are available to check a component of the total water balance. The performance of the interception Model was checked for the hardwood forest by plotting throughfall versus gross rainfall on a monthly basis for growing and dormant seasons. The predictions were then compared with some experimental regression equations.

Calculation of net rainfall—the difference be-

[8] See footnote 6, pg. 3.

Table 6.—*Average difference between stemflow and litter interception for a hardwood forest*

	Growing season (May-October)	Dormant season (November-April)
Average number of storms ______	78	84
Average rainfall ________inches__	21.20	16.40
Difference (S-L)[1] _________inches__	—.15	+.05
Relative to gross rainfall __percent__	.70	.30

[1]Stemflow minus litter interception.

tween litter interception and the sum of throughfall and stemflow—is the ultimate aim of most interception studies. Helvey and Patric (*13*) provide a regression equation relating throughfall to gross rainfall based on data from the North Appalachian Experimental Watershed Research Center.

The effect of stemflow and litter interception must now be considered. Helvey and Patric (*13*) quoted analyses of experimental data for these two processes. Table 6 shows the differences in stemflow and litter interception based on rainfall data from the North Appalachian Experimental Watershed Research Center. Stemflow and litter interception are of the same order in a hardwood forest so that throughfall is a good estimate of the amount of rainfall reaching the mineral soil.

Modification of the USDAHL Model to account for canopy interception was described on p. 6. The results of modeling interception for a hardwood forest are illustrated in figures 6 and 7 which show modeled throughfall plotted versus gross rainfall on a monthly basis for growing and dormant seasons. Because throughfall is the input to the mineral soil, modeled throughfall should be compared rather than interception. As a consequence the rest of the modeling depends on how accurately throughfall is calculated.

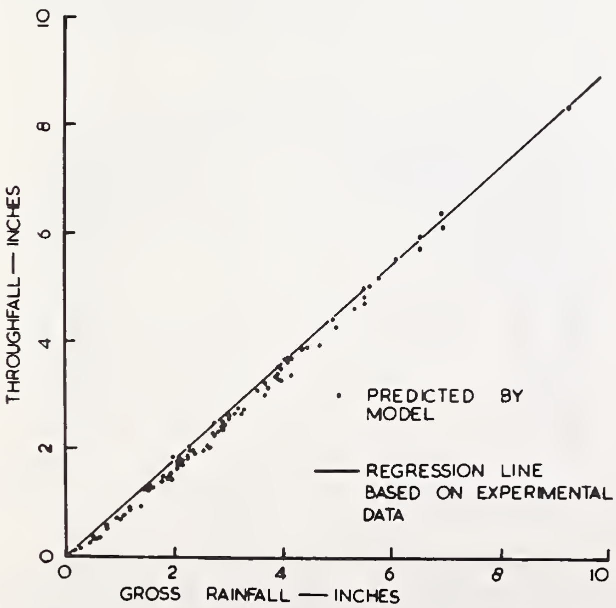

Figure 6.—Throughfall for eastern hardwoods—growing season.

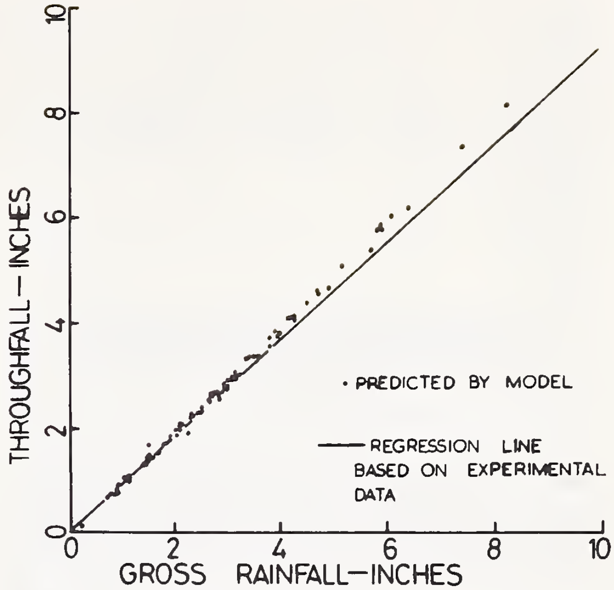

Figure 7.—Throughfall for eastern hardwoods—dormant season.

Interception data were not available for the pine forest on Watershed 172. Rogerson and Byrnes (*30*) and Marston (*25*) could find little difference between the water balances of hardwoods and pines in the growing season. The experiments involved red pine (*Pinus resinosa*) at a site in Pennsylvania and shortleaf pine (*P. echinata*) in Ohio. However, the pines accounted for greater water losses (evapotranspiration plus interception) in the dormant season. Helvey (*12*) could not find any seasonal variation in the interception of eastern white pine (*P. strobus*).

The average proportion of rainfall intercepted by the pine canopy on Watershed 172 in each month over the 16-year modeling is plotted in figure 8. The average annual proportion of rainfall intercepted by the pine canopy was 13.4 percent, and average proportion for white pine forest of similar basal area ranged from 13 to 16 percent (*12*).

A distinct seasonal pattern resulted in the modeled interception with lower proportions of water intercepted in the dormant season. Since the interception capacity was constant throughout the year, the seasonal pattern must have been caused by the seasonal variation in pan evaporation. Evi-

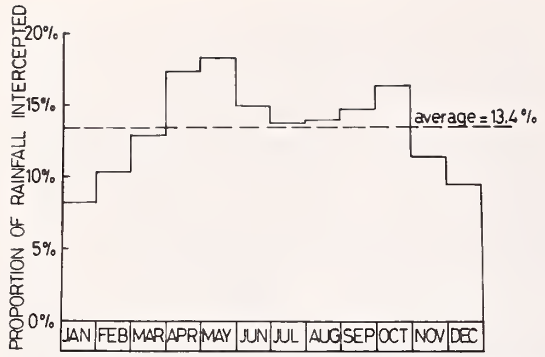

Figure 8.—Proportion of rainfall intercepted by a pine canopy on a monthly basis.

Table 8.—*Streamflow reduction after conversion to white pine for Watershed 1, Coweeta Hydrologic Laboratory*

Age	Basal area	Stocking rate	Streamflow reduction
Years	*Ft²/acre*	*Trees/acre*	*Inches*
10	32	720	[1]3.7
15	[2]104	713	[3]6.9
19	—	—	[4]8.0

[1]Swank and Miner (*32*).

[2]Compared to a basal area of 80 to 100 ft²/acre on Watershed 172.

[3]Swank and Schreuder (*33*).

[4]Swank and Douglass (*31*).

dence is available that evaporation from intercepted water in the dormant season can occur at several times the potential rate, Helvey (*12*). If a constant evaporation rate throughout the year had been used a more acceptable modeling might have been achieved. There would have been less seasonal pattern, and the annual proportion would have been in the required range from 13 to 16 percent.

Modeling of Hardwood and Pine Forests

Watershed 172 was covered with a mixture of pine and hardwood forest so the calibration could not consider the behavior of each forest type separately. As part of the modeling test, the crop parameters appropriate to hardwoods were used to simulate the hydrologic behavior of Watershed 172 for the 16-year calibration and test period, as though the watershed was completely covered with hardwood forest. The same procedure was followed for the pine forest. Table 7 shows the average annual water balances for 1950 to 1965.

The effects of converting a hardwood forest to white pine were discussed by Swank and Miner (*32*)

Table 7.—*Annual water balances (inches) for hardwoods and pines*

Forest	Rainfall	Evapotranspiration	Interception	Streamflow
Hardwoods	35.67	17.66	3.55	14.45
Pines	35.67	23.58	4.81	7.36
Difference				[1]7.09

[1]*Note:* the figures do not balance exactly. For example, 35.67—17.66—3.55=14.46 (not 14.45). The difference in water stored in the watershed at the beginning and the end of the modeling should also be included in the water balance. The 16 years of model simulation is long enough to ensure that differences in stored water can be safely neglected.

and Swank and Douglas (*31*). Table 8 shows the streamflow reduction after the establishment of the white pine plantation.

The average annual difference in streamflow of 7.09 inches between the modeled hardwood and pine forests (table 7) is compatible with the 6.9 inches measured after conversion of a hardwood forest to white pine. Watershed 1 at Coweeta and Watershed 172 at Coshocton both face south. If interception is the major factor causing the difference between the two species, then the difference between pine and hardwood at Coshocton could be smaller because of the lower rainfall.

Most of the decline in streamflow following conversion occurred in the dormant season and could be explained in terms of increased interception afforded by the pines during the season. The largest reductions in streamflow were during April, May, and June, when the hardwoods were leafing out. Not all of the reductions could be explained in terms of interception differences.

The transpiration of the hardwoods would be lower than the pines during leafing out. Figure 9 shows the differences in average monthly modeled streamflow for the hardwood and pine forests and compares the results with those of Swank and Douglass (*31*). The differences between the streamflows were greatest in the dormant season, particularly during the leafing out period. Interception did not make up for as much of the difference as the experimental watershed would indicate. Failure to use a higher evaporation rate during the dormant season could have been responsible for the smaller interception difference.

The modeling of hardwood and pine forests are considered adequate for the purposes of this study and compatible with available data.

Table 9.—*Parameters used for pine forest during reforestation period*

	Mature forest	1940	1941	1942	1943	1944	1945	1946	1947	1948	1949
Interception capacity ---inches--	0.03	0.003	0.006	0.008	0.011	0.014	0.016	0.019	0.025	0.025	0.025
Rooting depth ---------inches--	72	18	22	28	33	39	45	50	64	64	64
A value ----------------------	.5	.008	.07	.12	.16	.21	.26	.31	.45	.45	.45
ETEP ratio -------------------	1.2	.5	.58	.63	.74	.80	.86	.94	1.15	1.15	1.15

Modeling of Reforestation

This exercise aimed to demonstrate possible causes for changes in streamflow following reforestation. Because there were little or no data describing the increase in biomass of the growing pine forest, above and below the ground, the choice of crop parameters was somewhat arbitrary.

Four of the crop parameters were modified to simulate the growing pine forest:

(a) Interception capacity

(b) Rooting depth

(c) Basal area rating (*A* value) and

(d) ETEP, the parameter which controlled evapotranspiration, excluding interception.

The USDAHL Model allowed for nine crops—the hardwood forest and 8 separate age classes of pine could be described. Table 9 shows the crop parameters selected to describe the growing pine forest.

Instead of adjusting all the crop parameters at once, they were varied one at a time in the order listed above. Once a parameter was adjusted, it was left at the new value. The aim was to demonstrate that evapotranspiration as described by the last parameter on the list played an important role in reducing streamflow, and that changes in interception capacity, rooting depth, and basal area rating could not account for all the reduction.

The reduction in streamflow following reforestation was 7.3 inches over the whole watershed, or about 12 inches over the 60 percent of the watershed planted to pine. The remaining 40 percent was the original hardwood forest. This was too much to be explained in terms of increased interception of the pine forest over the eroded farmland.

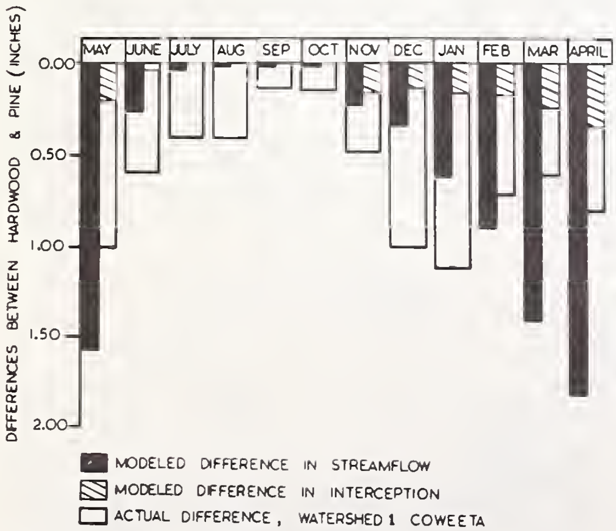

Figure 9.—Differences in streamflow from Watershed 172 under hardwood and pine forest.

Interception

If the evapotranspiration of the young pine forest was left at the same level as the mature forest, reducing the interception capacity had little effect on the water balance. . The extra water that reached the ground transpired because the trees lacked water in the growing season. From this test, apparently transpiration and interception would increase together until the canopy had fully closed.

Table 10 shows the calculated interception for the mature forest and growing forest. Reduction of the interception capacity by a factor of 10 only reduced the annual interception by one third.

Interception and Rooting Depth

Including a change in the rooting depth also had little effect on the overall water balance. In the first

Table 10.—*Calculated interception (inches) for the mature and growing pine forests*

Year	Annual Interception[1] Mature forest	Annual Interception[1] Growing forest	Reduction	Interception of growing pine forest
1940 ----------	6.46	4.31	2.15	0.003
1941 ----------	4.55	3.38	1.17	.006
1942 ----------	4.99	3.66	1.33	.008
1943 ----------	3.93	3.03	.90	.011
1944 ----------	4.16	3.39	.77	.014
1945 ----------	5.43	4.60	.83	.016
1946 ----------	4.87	4.31	.56	.019
1947 ----------	4.70	4.44	.26	.025
1948 ----------	4.69	4.43	.26	.025
1949 ----------	4.97	4.68	.29	.025

[1]Mixture of hardwood and pine forest as existed on Watershed 172. Only the parameters for the pine forest were modified.

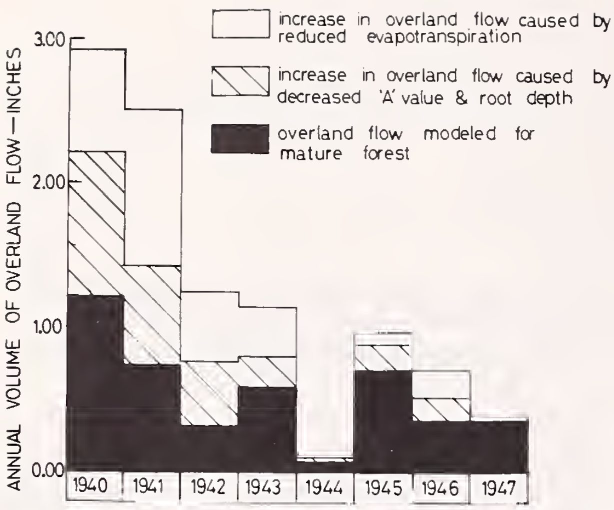

Figure 10.—Model simulated volumes of overland flow—reforestation period.

2 years rainfall was above average, particularly in summer, so the trees would not have been greatly restricted by the shallow roots. A more comprehensive analysis of the effect of rooting depth over a wide range of rainfall conditions is described on page 17.

Interception, Rooting Depth, and Basal Area Rating

In 1940, the first year of reforestation, the total increase in modeled annual streamflow was only 0.90 inch after reducing interception capacity, rooting depth, and basal area rating. Since the values of the parameters increased as the forest grew, the increase in streamflow decreased. By 1945 streamflow increase was negligible.

Although reducing basal area rating (reducing infiltration rates) in addition to interception capacity and rooting depth had little effect on the overall water balance, large increases occurred in the volume of overland flow reaching the stream as shown in figure 10. The volumes of evapotranspiration and interception determined the amount of storage space available in the soil. Changes in infiltration other than those caused by increased evapotranspiration only altered the path of water moving to the stream.

Interception, Rooting Depth, Basal Area Rating, and Evapotranspiration

After adjusting the value of the ETEP ratio for 1940 to give a water balance that matched the observed streamflow, values of the ratio in subsequent years were increased linearly. Flows for the 10-year reforestation were calculated with all four parameters adjusted in an attempt to model the hydrologic effect of the growing forest.

Figure 11 shows the deviations between model simulated and observed annual flows after adjustment of the parameters, figure 12 shows the modeled annual flows plotted versus the observed, and figure 13 shows the monthly hydrographs. The standard deviation of the errors of prediction was 1.51 inches, which was within the limit of accuracy of the Model as defined by the standard deviation of errors within the test period of 1.76 inches.

Thus, increased transpiration of the pines as

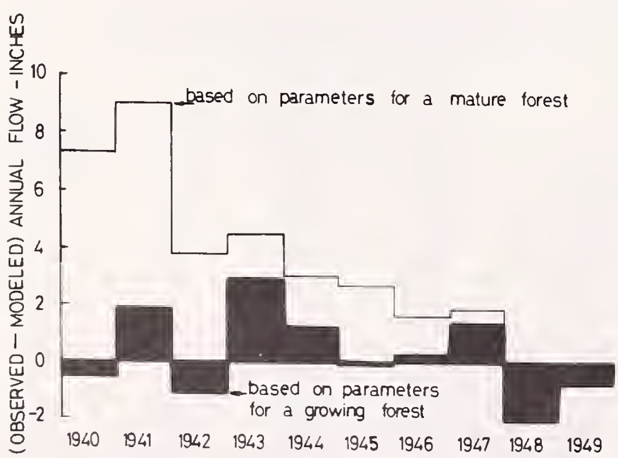

Figure 11.—Deviations between observed and model simulated flows—reforestation period.

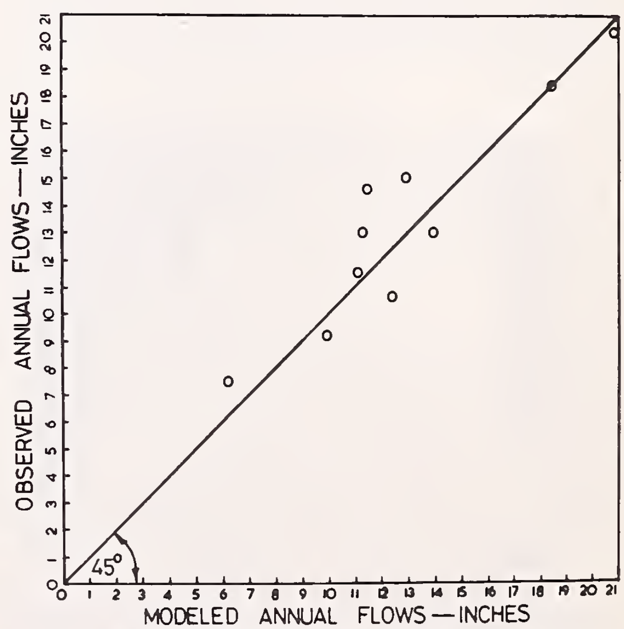

Figure 12.—Model simulated versus observed annual flows—reforestation period.

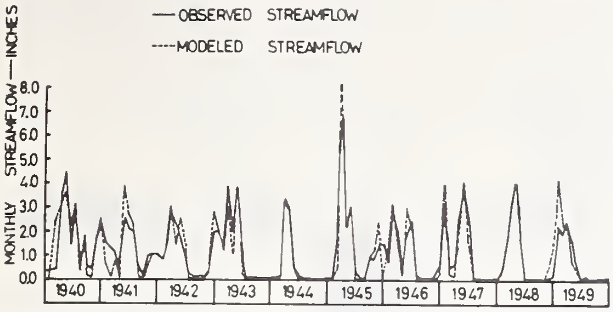

Figure 13.—Monthly hydrographs—simulation of reforestation period.

compared with the eroded pasture played an important role in reducing streamflow. Transpiration and interception would increase together as the forest grew, otherwise, increased interception would have little effect on the streamflow. In addition, figure 10 shows that infiltration increased markedly as the forest grew and that a considerable proportion of the increase was caused by the increased evapotranspiration lowering the levels of soil moisture as well as changes in soil properties.

Modeling Grass Cover

In addition to the experimental watersheds at the North Appalachian Experimental Watershed Research Center, data from monolith lysimeters were also available. Lysimeter Y101D situated in Muskingum silt loam was continuously operated from 1947 with vegetative cover of bromegrass and alfalfa (deep-rooted grass species). Relatively heavy applications of fertilizer and lime were made to this lysimeter.

England (*4*) used the USDAHL Model to study the hydrologic behavior of Lysimeter Y101D from 1948 to 1955. The Model used did not separate interception from transpiration. Table 11 shows the crop parameters that gave the best result. Table 12 shows the annual evapotranspiration measured by Lysimeter Y101D, the model simulated evapotranspiration, and the deviations between measured

Table 11.—*Crop parameters for Lysimeter Y101D (bromegrass and alfalfa)*

Crop parameter	Value
Basal area rating *A* value	0.70
Depression storage capacity ______inch	.25
Rooting depth ______inch	[1]96
ETEP ratio	1.25
Upper temperature limit (T_u) ______°F	78
Lower temperature limit (T_l) ______°F	20

[1]Depth of the lysimeter.

Table 12.—*Measured- and Model-simulated annual evapotranspiration (inches) from Lysimeter Y101D under bromegrass and alfalfa*

Year	Evapotranspiration Measured (A)	Evapotranspiration Simulated (B)	Difference (A) — (B)
1948	32.54	29.49	+3.05
1949	37.36	37.40	— .04
1950	36.94	32.46	+4.48
1951	37.19	35.82	+1.37
1952	35.69	37.43	—1.74
1953	31.90	30.12	+1.78
1954	31.99	29.60	+2.39
1955	36.00	34.65	+1.35
Mean	34.95	33.37	

and simulated evapotranspiration. The mean annual evapotranspiration was 34.95 inches, and the standard deviation of the differences between the measured and modeled evapotranspiration was 1.89 inches, or 5.4 percent of the measured evapotranspiration.

The major problem in using the lysimeter data was the large difference between watershed and lysimeter evapotranspiration, possibly caused by the advection of energy from surrounding areas to the lysimeter and the walls of the lysimeter preventing lateral seepage of water. Mustonen and McGuinness (*27*) calculated the ratio of lysimeter to watershed evapotranspiration for Watersheds 172 and 196. The average ratio was 0.68 for Watershed 196; unfortunately, Watershed 196 was not completely under grass cover, but it was the only watershed available under a continuous management practice.

Because the ratio of ETEP is used to calculate potential evapotranspiration for a given crop, the maximum ratio of watershed evapotranspiration to lysimeter of 0.76 was used to modify ETEP. This maximum value occurred under wet conditions when lack of moisture was unlikely to inhibit evapotranspiration. The value for ETEP of 1.25 derived by England was reduced to 0.95 (1.25 × 0.759) for model simulation with grass on Watershed 172.

The 16-year calibration and test period was used for assessing the simulation of Watershed 172 under grass cover. Table 13 shows the annual water balances for grass and hardwood forest. Hibbert (*15*) described the effect of converting a watershed from a hardwood forest to grass. The streamflow from grass that had been fertilized was the same as, or less than, the expected flow from the original

Table 13.—*Annual water balances (inches) for Watershed 172 under grass and hardwood forest*

Crop	Rainfall	Evapotranspiration including interception	Streamflow
Grass	35.67	21.70	13.90
Hardwood forest	35.67	21.21	14.45

forest. Grass water consumption was greater than the hardwood forest in the early spring when the hardwoods were leafing out and less during late summer.

Figure 14 shows the average differences between the monthly streamflow based on modeling of Watershed 172 under hardwood forest and grass. The grass consumed more water in the spring, particularly April and May; the hardwood forest consumed more in late summer and autumn. The modeling of Watershed 172 under bromegrass and alfalfa was compatible with the results described by Hibbert (*15*). In terms of seasonal pattern and absolute amount, although the results described by Hibbert are only for one watershed and type of grass, they represent the best evidence available for comparing the hydrologic behavior of grass and eastern hardwood forests under humid conditions.

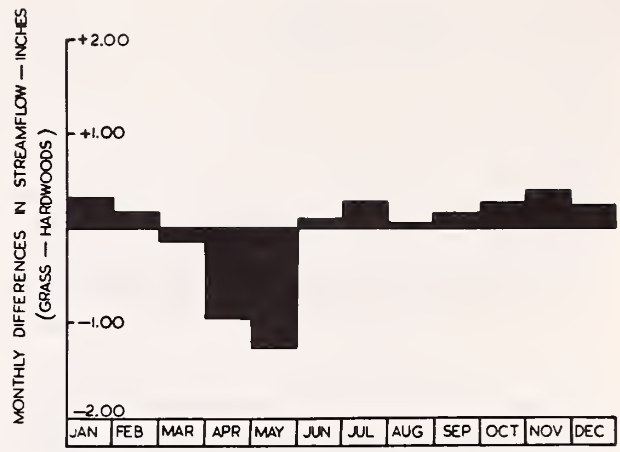

Figure 14.—Differences in model simulated streamflow from Watershed 172 under grass and hardwoods.

Comparison of Land-Use Policies Under a Range of Rainfall Conditions

The major aim of the study was to compare several land-use policies under a range of antecedent and post-treatment rainfall conditions. Experimental evidence indicates that changes in streamflow under different land management could be suppressed under dry conditions. If this suppression of streamflow change can be established, then questions can be raised of considerable importance to watershed management.

To set up a statistical experiment to compare policies, a series of artificial climatic sequences were arranged, and the effect of a number of land-use policies on streamflow calculated using the USDAHL Model. Because rainfall was of principal concern in this study, the climatic sequences were broken up into antecedent and post-treatment rainfall periods. Three antecedent periods (wet, average, and dry) and three post-treatment periods (also wet, average and dry) were combined to produce nine artificial sequences of climatic conditions.

The mixed hardwood and pine forest on Watershed 172 existing during the calibration period, formed a basis for calculating the streamflow changes. The first stage in the study was to compute the streamflow from Watershed 172 under mixed hardwood and pine forest for all nine sequences. The second stage was to repeat the calculations of streamflow for all nine sequences, after changing the crop parameters (land-use) at the end of antecedent period of each climatic sequence. The differences in streamflow during the post-treatment periods were taken as the change in streamflow, or response to the change in land-use. In all, five different land-use policies were considered in an analysis of variance designed to compare the five policies over a range of nine climatic sequences.

Selection of Antecedent and Post-Treatment Periods

Simmons[9] analyzed the effect of antecedent rainfall on the level in ground-water Well 157 located in Watershed 172. A linear regression was performed on the well levels on May 1, end of the dormant season, using totals of monthly rainfall starting with 1 month and building up to 30 months of antecedent rainfall. An 18-month period was found to give the best results. From Simmons' analysis, at least 18-months would be required to set antecedent conditions.

Water years were used as the basic unit of time since the May to April water year consisted of one

[9]See footnote 6, p. 3.

Table 14.—*Selection of antecedent and post-treatment periods*

Periods	Antecedent periods			Post-treatment periods	
	Years	Ground water level at end of April[1]	Total rainfall over the 2 water years	Years	Rainfall over 2 water years
		Feet	*Inches*		*Inches*
Wet ---	1957-58 1958-59	10.56	80.20	1950-51	45.53
Average	1963-64 1964-65	9.82	64.07	1944-45	35.96
Dry ---	1952-53 1953-54	8.73	58.41	1953-54	27.92

[1]The last water year of the 2-year antecedent period 1959, 1965, and 1954.

growing season (May to October) and one dormant season (November to April). A period of 2 water years was selected to set the antecedent conditions, and 1 water year to describe the post-treatment conditions. The USDAHL Model used calendar years as the basic unit of time, so that 4 calendar years of data were used to give the 3 water years required for statistical analysis.

Simmons was not able to find a significant trend in the water levels on May 1 from 1939 to 1967, indicating that reforestation did not have a significant effect on the ground water level at the end of the dormat season. Table 14 shows the water levels in Well 157 on May 1 for the water years selected as wet, average, and dry.

The post-treatment of 1 water year was selected

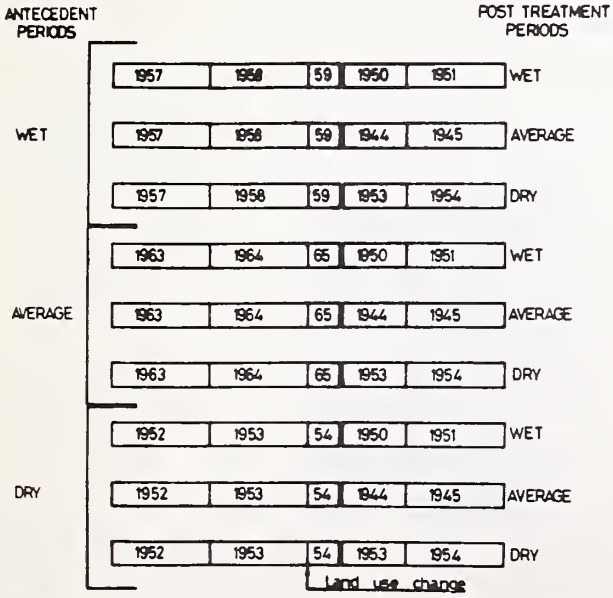

Figure 15.—Nine sequences of climate used in comparison of land-use policies.

on the basis of total rainfall over the water year as shown in table 14. The wettest, driest, and an average year were selected. The three antecedent periods and three post-treatment periods were combined to form the nine artificial sequences of climate as shown in figure 15. The USDAHL Model changed crop parameters at the end of a calendar year so that the land-use change was made after 2 calendar years as also shown in figure 15.

Land-Use Policies

In addition to the range of climatic conditions, a range of land-use policies was required to set up the statistical experiment. The policies were chosen to cover the range of practical alternatives for Watershed 172. The following policies were considered:

Policy 0 Mixed hardwood and pine forest on Watershed 172 existing during the calibration period.

Policy 1 The whole watershed was converted to deep-rooted grass. The crop parameters derived for the bromegrass-alfalfa mixture were used; rooting depth was 72 inches.

Policy 2 The whole watershed was converted to shallow-rooted grass. Crop parameters were the same as policy 1; rooting depth was 18 inches.

Policy 3 The forest in zones 2 and 3 was cut and replaced by deep-rooted grass. Effectively all the pines were removed and replaced by grass (a zone map is shown in figure 18). The crop parameters for the grass were the same as for policy 1.

Policy 4 The forest in zones 2 and 3 was cut and left bare except for the planting of pine seedlings. The crop parameters derived from the first year of the Model simulation of the 1940-49 reforestation were used for zones 2 and 3.

Policy 5 The watershed was developed as a recreational area. Table 15 shows the proportion of each zone covered by impervious material. The crop parameters for the roads were selected to set infiltration and evapotranspiration to zero.

Variation of Streamflow Increases with Rainfall

Table 16 shows the streamflow in inches over the post-treatment water years from the mixed hardwood and pine forest, for the nine sequences of climate, as well as the flows for the other five land-use policies.

The streamflows from Watershed 172 under the

Table 15.—*Recreational use (policy 5)*

	Percent of each zone covered with impervious material
Zone 1 ------------------------------	8
Zone 2 ------------------------------	9
Zose 3 ------------------------------	12
Zone 4 ------------------------------	0
Whole watershed -------------------	9

Table 16.—*Streamflows and responses to treatment (inches) for five policies under nine sequences of climate*

Antecedent conditions	Post-treatment conditions	Mixed hardwood and pine forest streamflow	Policy 1 Stream-flow	Policy 1 Re-sponse	Policy 2 Stream-flow	Policy 2 Re-sponse	Policy 3 Stream-flow	Policy 3 Re-sponse	Policy 4 Stream-flow	Policy 4 Re-sponse	Policy 5 Stream-flow	Policy 5 Re-sponse
Wet	Wet	19.31	24.22	4.91	25.15	5.84	23.70	4.39	27.77	8.46	20.80	1.49
	Average	10.13	12.51	2.38	14.04	3.91	12.88	2.75	16.81	6.68	11.22	1.09
	Dry	4.07	5.85	1.78	7.66	3.59	6.23	2.16	10.28	6.21	5.22	1.15
Average	Wet	19.02	23.90	4.88	24.88	5.86	23.38	4.36	27.52	8.50	20.55	1.53
	Average	9.80	12.13	2.33	13.67	3.87	12.49	2.69	16.55	6.75	10.92	1.12
	Dry	3.77	5.51	1.74	7.33	3.56	5.88	2.11	10.01	6.24	4.94	1.17
Dry	Wet	18.96	23.73	4.77	24.73	5.77	23.28	4.32	27.55	8.59	20.49	1.53
	Average	9.74	12.03	2.29	13.56	3.82	12.44	2.70	16.58	6.84	10.86	1.12
	Dry	3.09	5.29	1.60	7.15	3.46	5.75	2.06	10.05	6.36	4.88	1.19

mixed hardwood and pine forest illustrate the effect of the antecedent and post-treatment rainfall. As rainfall descreased in the post-treatment period, following wet antecedent conditions, streamflow decreased markedly from 19.31 to 10.13 to 4.07 inches. The antecedent conditions had a discernible but much smaller effect for the wet post-treatment period with streamflow declining from 19.31 to 19.02 to 18.96 inches as the antecedent rainfall decreased from wet to average to dry.

The more important effect of post-treatment rainfall over antecedent rainfall is not unexpected because the watershed is small, with relatively small capacity for storing ground water, and the soil mantle usually reached field capacity at the end of the dormant season, even under dry conditions. The carryover of soil moisture deficits from one year to the next was not an important feature of Watershed 172.

After an initial inspection, antecedent rainfall could have been neglected. However, a decision was made to include it in the analysis because one aim of the study was to develop a technique that could be applied to other watersheds. Conceivably, in watersheds with larger capacity for storing ground water and where carry over of soil moisture deficits from one year to another was an important factor, the antecedent conditions could be more important.

Streamflow increase after conversion to deep-rooted grass declined markedly with decrease in post-treatment rainfall and only slightly with the decrease in antecedent rainfall. The results showed that the lower the rainfall the smaller the increase in streamflow following treatment. For example, for wet antecedent conditions, the increase in streamflow following policy 1 declined from 4.91 to 2.38 and 1.78 inches as the post-treatment rainfall decreased from wet to average to dry.

In the study of the effects of rainfall on the change in streamflow, following a change in land-use, the discussion has been confined to policy 1, conversion of the forest to deep-rooted grass over the whole watershed. The other four policies showed similar trends.

An analysis of the water balances showed that rainfall in the growing season was the major factor controlling the change in streamflow following treatment. Figure 16 shows the evapotranspiration and interception for the mixed hardwood and pine forest and deep-rooted grass over the May to October growing season under wet, average, and dry post-treatment rainfall conditions (and wet antecedent conditions). As rainfall in the growing season decreased, the evapotranspiration of the grass increased relative to that of the forest, so that the difference in consumptive use decreased. Apparently the forest is less able to stand dry conditions than deep-rooted grass.

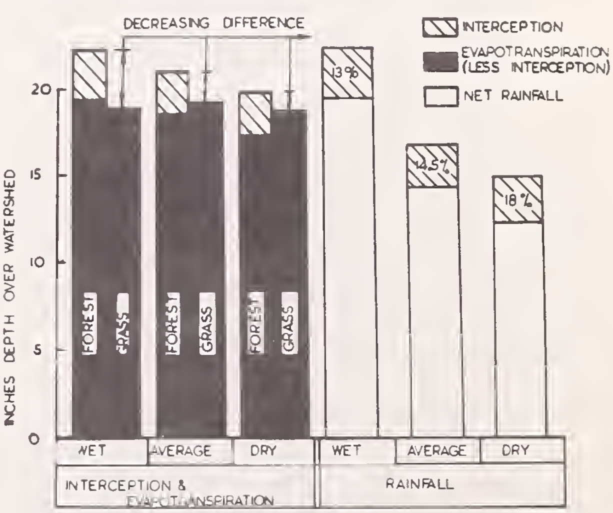

Figure 16.—Effect of decreasing rainfall during the growing season on consumptive use of forest and grass.

Figure 16 also shows the gross and net rainfall (rainfall minus canopy interception). The USDAHL Model as used in this study, considered the interception of rainfall by grass to be small and so all the rainfall was subjected to infiltration. Interception for grass was included with evapotranspiration. On the other hand, for the forest, interception was subtracted from gross rainfall and only net rainfall was subjected to infiltration. As a consequence, the root systems of crops with a higher interception capacity received less water than those with a lower capacity.

The calculation of evapotranspiration (excluding interception) in the model was based on the following equation:

$$ET = GI\ (ETEP)\ E_p[(S-SA)/AWC]^x$$

where ET = evapotranspiration in inches/day
GI = growth index
$ETEP$ = ratio of evapotranspirotion to pan evaporation
E_p = pan evaporotion in inches/day
S = total porosity
SA = avoilable porosity
$(S-SA)$ = amount of woter in the soil
AWC = porosity availoble for evapor-tronspiration (i.e. above wilting point) } expressed in inches for the total depth of topsoil
$x = 0.5$ for sonds
$= 1.0$ for finer textured soils

The term in brackets on the right-hand side is a soil moisture depletion function which progressively lowers the rate of evapotranspiration as the soil dries out.

Under wet conditions neither the forest nor the grass was limited for water, and evapotranspiration occurred at or near the potential rate with the difference in consumptive use essentially the interception difference. As rainfall in the growing season decreased, the difference between gross and net rainfall became more important. The soil moisture depletion function suppressed transpiration of the forest more than the grass because the grass received more water and consequently soil moisture levels were higher.

The distribution of rainfall in the wet growing season had a smaller number of heavier rainstorms; although the magnitude of the interception was greater, the proportion relative to gross rainfall was lower than for the dry growing season.

Because there are considerable practical implications if the change in streamflow is suppressed under conditions of low rainfall, a survey of experimental evidence was undertaken for experimental watersheds in the Eastern United States in a similar environment to Watershed 172.

Table 17.—*Suppression of water yield increase (inches) following elimination of vegetation*

Yeor	Growing Season (June to September)	
	Streomflow increase	Roinfall
1966	12.4	20.3
1967	9.3	18.3
1968	4.9	13.4

Pierce and others (*28*) and Hornbeck, Pierce and Federer (*19*) described the effect of elimination of vegetation on streamflow for a watershed in the Hubbard Brook Experimental Forest located in New Hampshire. The hardwood forest was clear-felled, and the regrowth suppressed with herbicides for 3 consecutive years so that essentially the same cover was maintained. Table 17 shows the flow increase for the three growing seasons after treatment. The majority of the change in streamflow at Hubbard Brook occurred during the growing season.

A marked decline in streamflow response with decreasing rainfall in the growing season can be seen. Unfortunately, the precipitation decreased in consecutive years after treatment. Possibly, regrowth was not entirely suppressed. The authors were of the opinion that this idea was not the case, and that rainfall in the growing season played an important role. The large difference in interception capacity between the original forest and the treated watershed could explain the suppression of yield increase with decreasing rainfall as mentioned above.

Lynch and Sopper (*24*) described the results of a similar experiment on a watershed at Leading Ridge, Pennsylvania. From January to April 1967, 27.3 acres at the lower end of Watershed 2 were clear-felled. During the summers of 1967 and 1968, the clear-cut area was sprayed with herbicides to restrict regrowth of all woody vegetation. Like Hubbard Brook, most of the increase in water yield at Leading Ridge occurs during the growing season. Streamflow increase during the growing season of 1967 was 2.3 inches compared with 0.96 inches in 1968. The rainfall in the growing season of 1968 was 4 inches less than for 1967. Lynch and Sopper (*24*) concluded that the lower rainfall during the growing season was a factor in the smaller streamflow increase but the incomplete inhibition of regrowth could also be a factor.

Kochenderfer (private communication)[10] indicated that on two of the watersheds in the West

[10]Jomes Kochenderfer, reseorch forester, Timber and Watershed Laboratory, U.S. Forest Service, Parsons, W. Va.

Table 18.—*Effect of land-use on average annual water balances, inches*[1]

Policy	Watershed cover	Rainfall	Evapotranspiration (excluding interception)	Interception	Evapotranspiration (including interception)	Total runoff	Subsurface flow	Surface runoff
0	Mixed hardwood and pine forest	36.46a	21.01a	4.46a	25.47a	10.94a	10.33a	0.61a
1	Whole watershed to deep-rooted grass	36.46a	22.54a	—— b	22.54ab	13.91 bc	13.27 bc	.64a
2	Whole watershed to shallow-rooted grass	36.46a	21.09a	—— b	21.09 b d	15.35 cd	14.53 c	.82a
3	Zones 2 & 3 to deep-rooted grass	36.46a	21.55a	.99 c	22.54ab	14.00 bc	13.34 bc	.66a
4	Zones 2 & 3 to eroded & re-planted pines	36.46a	16.22 b	2.05 d	18.27 d	18.13 d	14.06 bc	4.07 b
5	Recreational use	36.46a	20.10a	4.11a	24.21ab	12.21ab	11.47ab	.74a

[1]Means within a column followed by the same letter do not differ significantly at the 5 percent level according to Duncan's multiple range test.

Virginia Fernow Experimental Forest, where the effects of treatment were still evident when a dry year occurred, the streamflow increase was suppressed.

Analysis of Variance of Streamflow with Land-Use Change

The hydrologic effects of the land-use policies described in the preceding section were examined by an analysis of variance. Total streamflow, surface runoff, subsurface runoff, evapotranspiration and interception were all analyzed by this method. Appendix B describes in detail the statistical methods and results.

Analysis showed that the range of antecedent and posttreatment rainfall had little influence on the comparison of the policies. The year was broken up into six 2-month seasons in the analysis of variance. These 2-month seasons differed significantly from each other, as would be expected. In addition, there were significant interactions of seasons and policies for evapotranspiration and interception. A consistently significant interaction was found between seasons and treatment years, which indicated that the distribution of rainfall in the wet, average, and dry treatment years was dissimilar. The policies were compared under the same set of climatic conditions. Thus, the dissimilar distribution of rainfall in the posttreatment years would have little effect on the comparison.

There was no significant difference in the effect of the antecedent and post-treatment years and not much interest in the effect of seasons. The policies have been compared on an average annual basis and are listed in table 18.

The clear cutting of the forest in zones 2 and 3 followed by erosion and the planting of pines (policy 4) showed the largest increase in average streamflow. Zones 2 and 3 effectively represent the area on Watershed 172 planted to pines in 1939 so that this treatment put the watershed back into the same condiion as in 1940. Policy 4 is the only one that showed a significant difference in evapotranspiration (excluding interception), which supports the earlier conclusion that increased interception of the growing pine forest would not be sufficient to explain the change in streamflow, and that increased transpiration also played an important role.

In addition, policy 4 was the only one to show a significant difference in surface runoff. These conclusions support the earlier work of Harrold and others (*10*), who concluded that infiltration capacity was increased by the growing pine forest, and that increased interception and transpiration reduced streamflow. The erosion and subsequent deterioration in water quality would rule out policy 4 as a practical management alternative for increasing water yield.

Policy 2, complete removal of all the forest followed by planting of shallow-rooted grass, and policy 3, removal of the forest in zone 2 and 3 (effectively all the pine forest) followed by establishment of a deep-rooted grass, show the next largest

Table 19.— *Comparison of four land-use policies under a range of rainfall conditions*

Post treatment rainfall[1]	Policy 1		Policy 2		Policy 3		Policy 5	
	Yield increase	Relative to average year	Yield increase	Relative to average year	Yield increase	Relative to average year	Yield increase	Relative to average year
	Inches		*Inches*		*Inches*		*Inches*	
Wet	4.91	2.06	5.84	1.49	4.39	1.60	1.49	1.37
Average	2.38	1.00	3.91	1.00	2.75	1.00	1.09	1.00
Dry	1.78	.75	3.59	.92	2.16	.70	1.15	1.05

[1]Wet antecedent conditions

increases in water yield. These two policies were not significantly different although the shallow-rooted grass yielded more water. Policy 3 would have the advantage of giving the watershed a multi-purpose role: residual hardwood forest and high quality pasture and water. Policy 2 would only provide pasture of low productivity; the decreased productivity of the watershed would need to be weighed against the increase in water yield before a final management decision could be made.

Replacement of the pines with high quality pasture would appear to be the best management decision. Although differences in the comparison of policies caused by the post-treatment climate were not statistically significant at the 5 percent level, the effects of wet, average, and dry post-treatment conditions provide an interesting insight into the behavior of the various watershed covers. Table 19 shows the increases in streamflow for policies 1, 2, 3, and 5.

The increases in streamflow for the more drought-prone, shallow-rooted grass of policy 2 show less variation with post-treatment rainfall than those of the deep-rooted grass of policy 1. Policy 5, the recreational use, where 9 percent of the watershed was covered with impervious material, shows even less variation of yield increase with rainfall. The best watershed cover to have in a drought is one sealed, or partially sealed, because it produces an increase in streamflow in dry years much closer to the increase in average years.

The lower variation in streamflow increase with post-treatment rainfall, plus the larger average increase make the more drought-prone shallow-rooted grass an attractive proposition if water yield is the only management objective. The variation in streamflow increase should be considered in addition to the average increase when comparing several land-use policies.

Conclusions

Model Simulation Accuracy

The hydrology of Watershed 172 was simulated for 1940-71 by the USDAHL Model. Because earlier statistical studies showed little or no trends in streamflow, the 1950 to 1965 record was divided into an 8-year calibration and an 8-year test period. Crop parameters derived by optimization for the mixed hardwood and pine forest on Watershed 172 from the 8-year calibration were used to simulate the hydrology during the 8-year test from 1958 to 1965. Where possible the watershed parameters were derived from physical information and left fixed at their original values.

Standard deviation of the differences between Model simulated and observed annual flows was 1.46 inches or 13 percent of the mean flow for the calibration and 1.76 inches or 22 percent for the test. A rank correlation technique was used to test for trends in the annual errors for the calibration and test periods, separately and together as a continuous period. A significant but small trend existed in the errors for the calibration period. The earlier statistical studies had located a similar trend in this period. The trends in the test period and the calibration and test periods together were not significant.

Accuracy limits of the Model simulations were judged by doubling the standard deviation of the annual errors from 1957 to 1965. This limit of ±3.5 inches for a mean annual flow of 8.17 inches was compatible with a limit of ±3.3 inches calculated on the basis of a limit of ±5 percent in the rainfall measurement and ±5 percent in the calculation of evapotranspiration, including interception. When the accuracy of model simulation is improved, limits of measuring rainfall and calculating evapo-

transpiration should be tightened. Further attempts at improving the model simulation would be meaningless without an improvement in the accuracy and range of experimental data.

Comparison of Model Simulation Results with a Statistical Technique

A statistical method of predicting flows from Watershed 172 by using an adjacent control watershed was compared with the results of the Model simulation. The standard error of the deviations of the modeling was 30 percent greater than the regression standard error. Although the regression model required 26 years of data from two watersheds, the mathematical model required only 18 years of data for calibration.

Detection of Hydrologic Change

The Model detected changes in streamflow from Watershed 172 caused by reforestation and a change after 1966 by installation of a new weir or forestry operations. The changes detected by the mathematical Model agreed closely with the results of earlier statistical studies. For example, the decline in streamflow from 1940 predicted by the Model simulation was 7.3 inches compared to 7.19 inches predicted by the statistical study of Simmons.[11]

Model simulation was not a more accurate method of detecting change, but it did provide a viable alternative to purely statistical studies.

Modeling of the Reforestation

Model simulation of the hydrologic changes caused by the growing forest demonstrated that transpiration was important and that transpiration and interception increased as the pine forest grew. Although increasing rooting depth and basal area rating (increasing infiltration) did not have an important effect on annual streamflow, they did cause an important decrease in surface runoff. In addition, increasing transpiration caused a large increase in the amount of water infiltrating because the soil was drier. Interaction studies of hydrological components (infiltration and evapotranspiration, and transpiration and interception) demonstrate the advantages of mathematical modeling over statistical methods.

Comparison of Hardwoods, Pines, and Grass

The modeling study of Watershed 172 involved calibration of a mixed hardwood and pine forest. As part of the Model test, the hardwood and pine forests were studied separately. In addition, a pasture of bromegrass and alfalfa was studied using lysimeter and watershed data—the results were compatible with the experimental data. The difference between hardwood and pine forest was over-emphasized for the rainfall conditions. In the spring, leafing out of hardwoods was of major importance in determining streamflow differences between hardwoods and the other two crops.

Variations of Streamflow Changes with Rainfall

Five land-use policies were tested under nine combinations of rainfall from wet antecedent and wet post-treatment conditions to dry antecedent and dry-post treatment conditions. Results show that the lower the rainfall in the growing season after treatment the lower the streamflow response to land-use change. For example, the streamflow response to replacing the mixed hardwood and pine forest with high quality pasture decreased from 4.91 inches to 2.38 inches and 1.78 inches as the rainfall in the growing season decreased. As expected for Watershed 172, antecedent conditions had only a small influence on the response to land-use change. The difference between the mixed hardwood and pine forest and the pasture was caused by the difference in interception between the pines and the grass.

An analysis showed that the crops with lower canopy interception could extract and transpire more water under dry conditions because more water reached the roots. In addition, interception differences were not as great under low rainfall because differences in streamflow caused by differences in canopy interception are suppressed under dry conditions. Another explanation is that differences in transpiration caused, for example, by differences in transpiring biomass become evident only when enough water reaches the plant.

Available data from other experimental watersheds were examined and evidence supported the results; for example, low rainfall conditions suppressed streamflow changes.

Because dry years dominate reliability studies of water supply systems, increases in water yield following a change in land-use could be much lower than indicated by the average increase. Sufficient storage capacity in the water supply system, how-

[11] See footnote 6, p. 3.

ever, would hold the large streamflow increases in wet years for use in dry years. Conversely, a change in management policy that reduced streamflow, such as planting pine forests, would not cause as large a reduction of available water. The lower the rainfall of a region, the larger and more important would be the suppression of streamflow changes.

Comparison of Land Management Policies

Five alternative land-use policies for Watershed 172 were examined under nine rainfall conditions in an analysis of variance. At the 5 percent level, significant differences were found between the average responses to the various policies. For example, the mean annual flow from the mixed hardwood and pine forest was 10.94 inches, which was significantly different from the yield of 14.00 inches following replacement of the pines with high quality pasture. The antecedent and post-treatment conditions did not have a significant effect.

In terms of increased streamflow and significance of these increases, modeling study benefits were evaluated for making rational management decisions. Final selection of an optimum management policy would depend on other factors such as relative economic benefits gained from the forests and pasture.

Comparing several management policies demonstrated the advantages of a Model supported by statistical methods. Furthermore mathematical modeling of the whole hydrological cycle provided a useful framework for quantitative assessment of the hydrological implications of a management decision rather than more detailed consideration of only one or two aspects. Despite the limitations, present models still provide the most promising approach to the solution of land management problems.

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Appendix A

English to Metric Units of Measure

Table 20.—*Factors for converting from English to metric units of measure*

To convert	Into	Multiply by
Miles	Kilometers	1.609
Acres	Hectares	.4047
Feet	Meters	.3048
Inch	Millimeters	25.40
Fahrenheit	Centigrade	(F°—32)×5/9

Appendix B

Ideally, all parameters should be based on measurement. However, the variability of field data and the difficulty of measuring some of the parameters of the USDAHL Model made compromise necessary. All available information on Watershed 172 was assembled and reviewed in an effort to ensure correct modeling of the essential watershed characteristics.

Watershed Parameters

Zoning

One of the distinctive features of the USDAHL Model divides a watershed into subareas or hydrologic response zones. The basic zoning aim divides a watershed into areas which are as homogeneous as possible. Topography and soils are considered of major importance. After calculations of evapotranspiration, infiltration, and depression storage, excess surface water from each zone cascades to the next zone in the sequence or diverts into the stream or onto the alluviums next to the stream.

Figure 17 shows a topographic map of Watershed 172 and figure 18 shows a soil map. Ideally the hydrologic response zones should encompass only one soil type, but the need to maintain a correct zone sequence for cascading overland flows means compromise. The zones must be in numerical

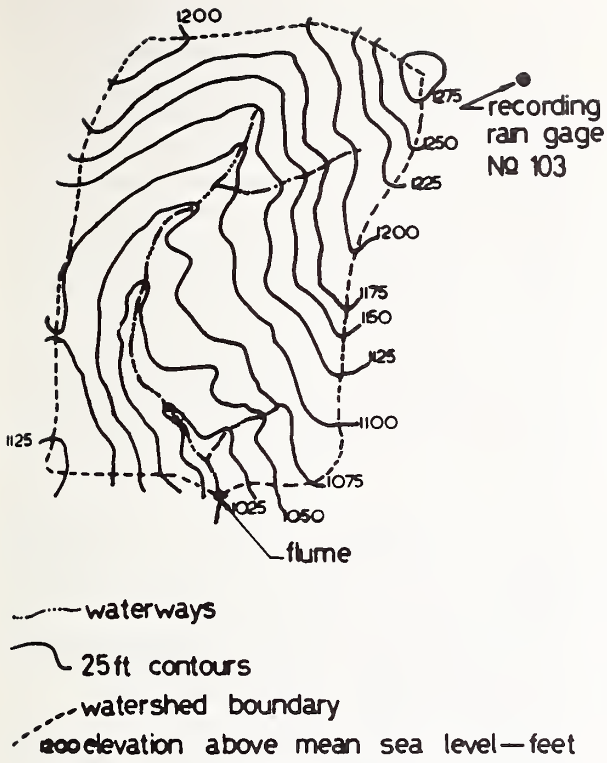

Figure 17.—Topographical map of Watershed 172.

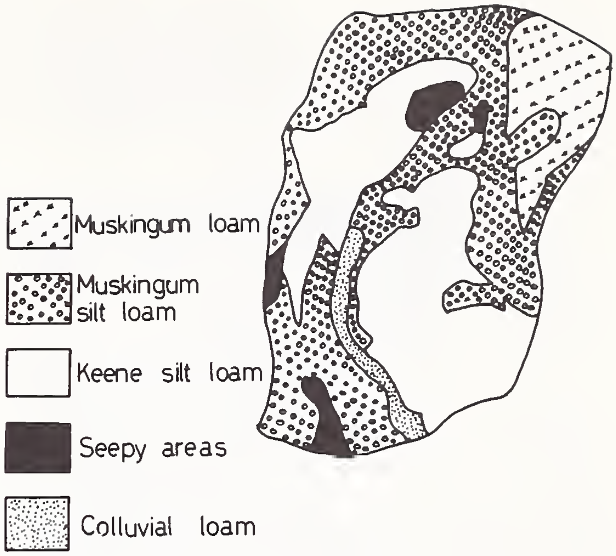

Figure 18.—Soils map of Watershed 172.

order from ridge to stream; for example, zones 1, 2, and 3 or zones 1, 3, and 4 are correct sequences, but zones 1, 3, and 2 are not.

Watershed 172 was divided into four hydrological response zones (fig. 19), and each zone was selected on the basis of the major soil type:

Zone 1—Muskingum loam
Zone 2—Muskingum silt loam
Zone 3—Keene silt loam
Zone 4—Calluvium (seepy areas and a land strip next to the stream channel)

Soils

The USDAHL Model requires that the soil profile be divided into two layers so that the total depth of soil is sufficient to include the deepest root systems. The top soil or upper layer was interpreted as the layer where the plants draw the majority of their moisture.

Infiltration and moisture-holding capacity are the two hydrologic properties described numerically. The percentage of cracks, and the final steady rate of infiltration into a saturated soil are required to calculate infiltration. The moisture-holding properties are described by G, the percentage by volume of water in the soil between field capacity (0.3 bar tension) and saturation, and the available water capacity, AWC, the percentage by volume between field capacity and wilting point (15-bar tension).

Principal features of the soil types in each zone were as follows:

(a) Zone 1—*Muskingum loam (Hartsells loam)* yellowish-brown loam to a depth of 3 feet. Below this depth the profile grades into a mixture of loose sand and soft coarse grained sandstone.

(b) Zone 2—*Muskingum silt loam (Gilpin silt loam)* light yellowish-brown silt loam, 9-inch layer, grading into a silty clay loam to 3 feet. The subsoil is a fractured siltstone and silty shale of moderate permeability.

(c) Zone 3—Keene *silt loam* topsoil texture similar to Muskingum silt loam at 21 inches; grades into yellowish-brown clay of slow permeability, which grades into bedrock at 50 to 60 inches.

The principal difference between these soil types lies in the subsoils: the Muskingum loam is underlain by a thick layer of highly permeable sand, the

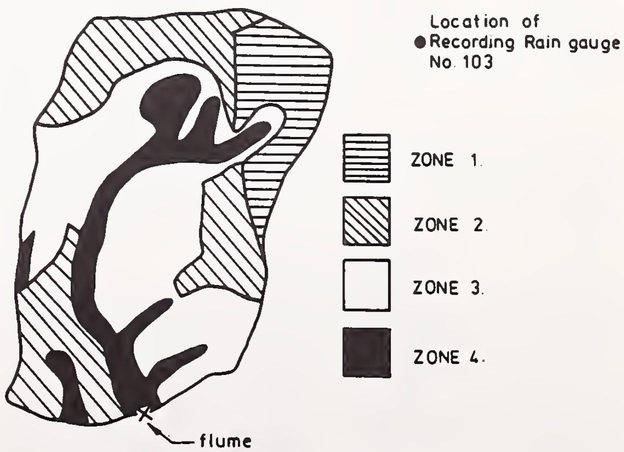

Figure 19.—Zone map of Watershed 172.

Muskingum silt loam by a layer of fractured silt stone and silty shale of moderate permeability, and the Keene silt loam by clay of low permeability. In addition, the topsoil of the Keene silt loam is shallower than the other two soils.

The soil properties measured in laboratory tests are highly variable even from samples within the same soil type. The aim of the numerical description of the soil types was to capture the major hydrological differences.

In situ measurements of soil moisture profiles were used to calculate G and AWC in preference to the results of the laboratory tests. Harrold and Dreibelbis (*10*) described soil moisture profiles measured in monolith lysimeters, of Muskingum and Keene silt loam soil types. No important differences in soil moisture extraction was measured between the two soil types down to 21 inches. Beyond 21 inches, the Keene soil was wetter, which reflected the heavier subsoil. At the end of the growing season, the soil moisture profiles in the Muskingum silt loam showed marked changes at 36 inches where the soil became wettest for deep and shallow-rooted crops. Thickness of the two soil layers is shown in table 21. The remaining values in this table are explained in subsequent pages.

G and AWC values were based on total soil moisture in the first 40 inches of Muskingum silt loam by Mustonen and McGuinness (27). Between 1951 and 1954, the profiles were examined and a 5 percent moisture value was given to the wilting point and 34 percent to field capacity. The total porosity of 39 percent was based on laboratory tests on the same soils and values of G and AWC were taken as 5 and 29 percent respectively. Because of the similar topsoils of the Muskingum and Keene silt loams, the same G and AWC values were used for both. In addition, Harrold and others (*11*), showed that there were no important differences between the soil moisture retention characteristics of Muskingum loam and Muskingum silt loam; so G and AWC values of 5 and 29 percent were used for the loam topsoil also.

G and AWC values for the subsoils (table 21) were derived from the following sources:

(a) *Zone 1,* from table 3, Holtan and Lopez (*17*)

(b) *Zones 2 and 4,* from soil moisture retention data based on laboratory measurements, Holtan and others (*16*)

(c) *Zone 3,* from the same source as Zones 2 and 4

Table 21.—*Watershed parameters*

	Acres	Number of zones	Number of routing regimes	Number of crops	Deep groundwater recharge in/hr	Land use change	Tillage Change	GI curves Input	
Watershed	43.6	4	4	2	0	No	No	True	
	Number	Watershed *Percent*	Length *Feet*	Slope *Percent*	FC *In/ Hr*	Top soil *Inch*	Total soil *Inch*		
Zone	1	12	400	30	0.20	36	72		
	2	32	440	25	.10	36	72		
	3	42	340	20	.05	24	50		
	4	14	60	10	.15	36	72		
	Number	G_1 *Percent*	AWC_1 *Percent*	ASM_1 *Percent*	$Cracking_1$ *Percent*	G_2 *Percent*	AWC_2 *Percent*	ASM_2 *Percent*	$Cracking_2$ *Percent*
Soils	1	5	29	17	5.3	1	15	10.0	2.4
	2	5	29	17	2.9	14	20	10.0	5.3
	3	5	29	15	0	19	13	18.9	4.5
	4	5	29	15	2.9	14	20	10.0	6.3
	ΔT Hrs	M_c Hrs	Initial In/Hr						
Channel	.10	.7	.000109						
	Avg ET In/Day	q_1 In/Hr	m_1 Hrs	q_2	m_2	q_3	m_3	q_4	m_4
Subsurface	.003	.17	3.3	0.027	37.8	0.0076	104		
	Subflow diverted to channel *Percent*	Z_1 Cascading Z_2 *Percent*	Remainder	Z_2 to Z_3 *Percent*	Remainder	Z_3 to Z_4 *Percent*	Remainder		
Cascading	30	70	Channel	60	Alluvium	30	Alluvium		

The percentage cracking in table 21 was calculated by Holtan and Lopez (*17*) from the data by Holtan and others (*16*).

Final steady rates of infiltration were based on a soil classification system described by Musgrave (*26*). Major factors for selecting the numerical values within the range quoted by Musgrave were:

(a) Zone *1*—0.2 in/hr., lighter textured topsoil; subsoil is highly permeable sand.

(b) Zone 2—0.1 in/hr., heavier topsoil and subsoil than the Muskingum loam of zone 1.

(c) Zone *3*—0.05 in/hr., shallower topsoil; relatively impermeable subsoil of the Keene silt loam.

(d) Zone *4*—0.15 in/hr., deeper alluviums around the stream than soil on the hill slopes.

Routing

Holtan and Lopez (*17*) described how they obtained the routing parameters from recession curves plotted on semilogarithmic scales. In all, four routing parameters were used: m_c for the stream channel, m_1 for the first layer of soil, m_2 for the second layer of soil, and m_3 for the deeper ground water storage.

The measured recessions from Watershed 172 were variable even though recessions occurring in the winter months were selected to keep evapotranspiration to a minimum. The routing parameters were calculated from a recession which formed an upper limit for recessions plotted. Figure 20 shows the values calculated for the routing parameters—the value of 104 hours for m_4 was compatible with the values calculated by Harrold and others (*11*).

The parameters required to cascade overland flow from zone to zone were calculated from a study of subcatchments within zones. Figure 21 shows the basis for cascading the overland flow from zone 1 to zone 2 and diverting the remainder to the channel.

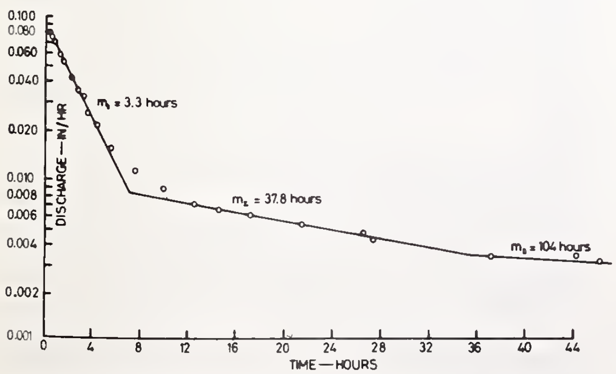

Figure 20.—Recession curve used to calculote routing parameters.

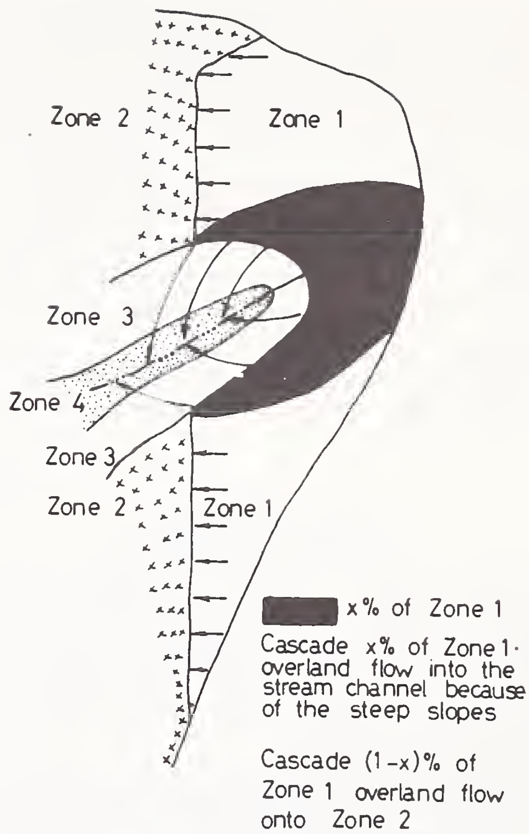

Figure 21.—Cascading overland flows.

The percentage of subsurface flow diverted to the stream was based on the assumption that approximately 30 percent of the stream channel was in the steep upper reaches of the watershed and about 70 percent in the flatter lower reach. The ground water in the lower reach would be more likely to be subject to evapotranspitation from riparian vegetation: 70 percent of the subsurface flow was therefore diverted to the alluviums around the stream.

The length of a zone, calculated by taking the average length of a zone around the contour and the average slope from the contour map, was used to cascade the overland flow.

The seepage to deep ground water was set to zero on the basis of geological information gathered by Urban (*35*).

Crop Parameters

For modeling purposes the forests on Watershed 172 were separated into pines and hardwoods.

Two crop parameters modify infiltration. The *A* value or basal area rating is a measure of the surface connected porosity and shows a value between 0.0 and 1; the higher the *A* value the higher the

initial rate of infiltration. For the hardwood forests that have a layer of decomposing litter and a dense understory of shallow-rooted plants, the *A* value was 1. Holtan and Lopez (*17*) suggested an *A* value of 1 for good quality forests. The pine forest had a denser canopy that excluded the light and suppressed the development of an understory. In addition, the pine needles did not decompose readily leaving a more definite boundary between the litter and the mineral soil. For these reasons, a lower *A* value of 0.5 was selected.

Depression storage formed the other surface parameter. The depth of water stored in the depressions was 0.05 inches for both forests. This value was based on a recommendation by Holtan and Lopez (*17*) for surfaces of agricultural lands and some experimental results described by Langford and Turner (*23*).

Roots grew the full depth of the soil profile because they were found at these depths in the sides of pits dug during the soil survey—72 inches for the Muskingum soils and 50 inches for the Keene.

Parameters describing the amount and seasonal distribution of evapotranspiration were evaluated by calibrating the model against observed streamflow.

Appendix C

Analysis of Variance

The hydrologic effects of the land-use policies described on p. 17 were examined for nine sequences of climate by an analysis of variance. Total runoff, surface runoff, subsurface runoff, evapotranspiration (excluding interception), and interception were all analyzed.

The most difficult decision in structuring the analysis of variance involved the selection of an appropriate error term. Monthly totals of the hydrologic factors were available for 12-months. Some consideration was given to dividing the data into a May-October growing season and a November-April dormant season and use of the variance of months within seasons as the error term. This error would have been grossly inflated however, because average precipitations of 4.53 and 2.17 inches for July and October would be contrasted.

The final decision divided the data into six 2-month seasons (May-June, July-August and soforth) and used the variance of the months within seasons as the error term. Adjacent months' data tend to minimize the variance caused by the periodic component responsible for the seasonal pattern of hydrologic data. A more realistic error term could be constructed if the treatment periods were simulated over additional years but not without a sharp increase in computing costs.

The measured streamflow from reforested Watershed 172 provided a check on the suitability of the error term for the simulation experiment. Monthly totals during the mature period from May 1950 through April 1965 were analyzed, and the months-within-seasons error term for these 15 years of measured data was less than half that obtained with the simulated runoff. These data indicate that the simulated data error term is inflated, and that any conclusions drawn about the statistical significance of effects are on the conservative side, at least for total runoff.

The structural analysis and the expectations of mean squares in the analysis of variance are shown in table 22. Seasons and months in seasons are random since seasons represent a grouping of months and months are considered random. Policy effects are fixed because inferences will be made only for the six policies included. The climate in the antecedent and the treatment years are also considered fixed because they form nine combinations of fairly distinct climatic situations. Under these combinations of antecedent and treatment year climates, the experiment is designed to determine how the policies compare.

The six policies compared with the single degree of freedom technique were:

Policy 0 Mature forest of mixed hardwood and pine

Policy 1 Deep-rooted grass

Policy 2 Shallow-rooted grass

Policy 3 Zones 2 & 3 in deep-rooted grass with rest of watershed in mature forest

Policy 4 Zones 2 & 3 eroded and replanted with rest of watershed in mature forest

Policy 5 Recreational use

The five individual degrees of freedom comparisons were:

1. Complete watershed treatment (policies 0, 1, 2, and 5) versus partial treatment (policies 3 and 4)
2. Forest cover (policies 0 and 5) verses grass cover (policies 1 and 2)
3. Forest (policy 0) verses recreational use (policy 5)
4. Deep-rooted grass (policy 1) versus shallow-rooted grass (policy 2)
5. Partial deep-rooted grass (policy 3) versus partial eroded and replanted (policy 4)

Table 22.—*Structural analysis and the expectation of mean squares*

Source of variation	D.F.	Type	Expectation of Mean Square, Subscripts of σ^2: msyap	syap	sya	syp	sap	sy	sa	sp	s	yap	ya	yp	y	ap	a	p
GT	msyap																	
CFM	1																	
T (C)	msyap-1																	
Policies (P)	p-1	Fixed	X	x	-	x	x	-	-	X	-	x	-	x	-	x	-	X
Antecedent conditions (A)	a-1	Fixed	X	x	x	-	x	-	X	-	-	x	x	-	-	x	X	
P × A	(p-1) (a-1)		X	x	-	-	X	-	-	-	-	x	-	-	-	X		
Years (treatment climate) (Y)	y-1	Fixed	X	x	x	x	-	X	-	-	-	x	x	x	X			
Y × P	(y-1) (p-1)		X	x	-	X	-	-	-	-	-	x	-	X				
Y × A	(y-1) (a-1)		X	x	X	-	-	-	-	-	-	x	X					
Y × P × A	(y-1) (p-1) (a-1)		X	X	-	-	-	-	-	-	-	X						
Seasons (S)	s-1	Random	X	x	x	x	x	x	x	x	X							
S × P	(s-1) (p-1)		X	x	-	x	x	-	-	X								
S × A	(s-1) (a-1)		X	x	x	-	x	-	X									
S × Y	(s-1) (y-1)		X	x	x	x	-	X										
S × P × A	(s-1) (p-1) (a-1)		X	x	-	-	X											
S × Y × P	(s-1) (y-1) (p-1)		X	x	-	X												
S × Y × A	(s-1) (y-1) (a-1)		X	x	X													
S × Y × P × A	(s-1) (y-1) (p-1) (a-1)		X	X														
Months within Seasons (M)		Random	X															

X is a valid component.

x does not exist when S and M are random effects and P, A, and Y are fixed.

- indicates component does not exist.

This orthogonal set of contrasts was selected before analyses.

As a further aid, Duncan's (3) multiple range test evaluated the policy differences. This multiple comparison test determines which treatment mean differs from the others.

Results of the analyses of variance in tables 23 through 28 show total runoff, surface runoff, subsurface runoff, evapotranspiration, interception and evapotranspiration (excluding interception). For each analysis, the denominator for F-test column lists the appropriate error term. Mean monthly policy values are listed at the bottom of each table along with significant differences as determined by Duncan's multiple range test.

Treatments caused a significant difference in total runoff, surface runoff, subsurface runoff, evapotranspiration, and interception evaporation. As contrasted with partial watershed treatment, treatments over the whole watershed generally caused a difference in the hydrologic elements. Except for surface runoff and evapotranspiration, forest cover differed from grass cover. Within the partial area treatments, deep-rooted grass differed from the eroded and replanted condition except for subsurface runoff.

Rainfall in the years antecedent to treatment and in the treatment years were selected to be wet, average, and dry. The analysis showed little influence from these varying inputs.

The six 2-month seasons, which made up the year, differed significantly among themselves, as expected. There were significant interactions of seasons and policies for evapotranspiration and interception evaporation. A consistently significant interaction was found between seasons and treatment years. This indicates that the distribution of rainfall in the wet, average, and dry treatment years was dissimilar.

Since there was no real difference in the effects of the years antecedent to treatment and the treatment years, and not much interest in the effects of seasons *per se*, the policy effects have been computed on an annual average basis and are listed in table 18.

TABLE 23. - ANALYSIS OF VARIANCE, TOTAL RUNOFF, INCHES

ASSUMING ALL VARIATES FIXED EXCEPT SEASONS AND MONTHS

SOURCE OF VARIATION	DEGREES OF FREEDOM	SUMS OF SQUARES	MEAN SQUARE	DENOM. FOR F-TEST	F 1/	F05	F01
GRAND TOTAL	648	3034.7079					
CORRECTION FOR MEAN	1	893.5408					
TOTAL CORRECTED	647	2141.1671					
POLICIES P	5	23.5602	4.71	SXP	6.53**	2.60	3.86
0512 VS. 34	1		8.79	SXP	12.18**	4.24	7.77
05 VS. 12	1		6.99	SXP	9.69**	4.24	7.77
0 VS. 5	1		.60	SXP	<1	4.24	7.77
1 VS. 2	1		.78	SXP	1.08	4.24	7.77
3 VS. 4	1		6.39	SXP	8.86**	4.24	7.77
ANTECEDENT COND. A	2	.1290	.06	SXA	<1	4.10	7.56
P X A	10	.0068	.00	SXPXA	<1	2.02	2.70
TREATMENT YEARS Y	2	220.2766	110.14	SXY	2.05	4.10	7.56
Y X P	10	1.0740	.11	SXYXP	<1	2.02	2.70
Y X A	4	.0005	.00	SXYXA	<1	2.87	4.43
Y X P X A	20	.0007	.00	SXYXPXA	<1	1.68	2.06
SEASONS S	5	788.6245	157.72	M	95.75**	2.23	3.06
GROW. VS. DORM.	1		397.07	M	241.04**	3.86	6.70
WITHIN GROWING	2		11.98	M	7.27**	3.02	4.66
WITHIN DORMANT	2		183.79	M	111.57**	3.02	4.66
S X P	25	18.0402	.72	M	<1	1.54	1.84
S X A	10	1.0494	.10	M	<1	1.85	2.37
S X P X A	50	.0718	.00	M	<1	1.39	1.59
S X Y	10	536.0791	53.61	M	32.54**	1.85	2.37
S X Y X P	50	18.4482	.37	M	<1	1.39	1.59
S X Y X A	20	.0446	.00	M	<1	1.60	1.93
S X Y X P X A	100	.0318	.00	M	<1	1.26	1.39
MONTHS W/I SEAS. M	324	533.7298	1.65				

POLICY	AVG. MONTHLY VALUE, INCHES	STATISTICAL SIGNIFICANCE 2/
0. FOREST	0.91	A
1. DEEP-ROOTED GRASS	1.16	B C
2. SHALLOW-ROOTED GRASS	1.28	C D
3. ZONES 2 & 3* DEEP GRASS	1.17	B C
4. ZONES 2 & 3* ERODED & REPLANTED	1.51	D
5. RECREATION	1.02	A B

1/ * AND ** INDICATE MEANS DIFFER SIGNIFICANTLY AT THE 5 AND 1 PERCENT LEVELS, RESPECTIVELY.

2/ MEANS FOLLOWED BY THE SAME LETTER DO NOT DIFFER SIGNIFICANTLY AT THE 5 PERCENT LEVEL ACCORDING TO DUNCAN S MULTIPLE RANGE TEST.

TABLE 24. - ANALYSIS OF VARIANCE, SURFACE RUNOFF, INCHES

ASSUMING ALL VARIATES FIXED EXCEPT SEASONS AND MONTHS

SOURCE OF VARIATION	DEGREES OF FREEDOM	SUMS OF SQUARES	MEAN SQUARE	DENOM. FOR F-TEST	F 1/	F05	F01
GRAND TOTAL	648	65.4873					
CORRECTION FOR MEAN	1	7.1044					
TOTAL CORRECTED	647	58.3829					
POLICIES P	5	7.1461	1.43	SXP	13.13**	2.60	3.86
0512 VS. 34	1		2.77	SXP	25.47**	4.24	7.77
05 VS. 12	1		.00	SXP	<1	4.24	7.77
0 VS. 5	1		.01	SXP	<1	4.24	7.77
1 VS. 2	1		.01	SXP	<1	4.24	7.77
3 VS. 4	1		4.35	SXP	39.98**	4.24	7.77
ANTECEDENT COND. A	2	.0010	.00	SXA	<1	4.10	7.56
P X A	10	.0005	.00	SXPXA	1.31	2.02	2.70
TREATMENT YEARS Y	2	4.5600	2.28	SXY	3.14	4.10	7.56
Y X P	10	1.6921	.17	SXYXP	1.27	2.02	2.70
Y X A	4	.0017	.00	SXYXA	<1	2.87	4.43
Y X P X A	20	.0007	.00	SXYXPXA	1.00	1.68	2.06
SEASONS S	5	1.1681	.23	M	2.78*	2.23	3.06
GROW. VS. DORM.	1		.04	M	<1	3.86	6.70
WITHIN GROWING	2		.26	M	3.08*	3.02	4.66
WITHIN DORMANT	2		.30	M	3.62*	3.02	4.66
S X P	25	2.7215	.11	M	1.30	1.54	1.84
S X A	10	.0049	.00	M	<1	1.85	2.37
S X P X A	50	.0019	.00	M	<1	1.39	1.59
S X Y	10	7.2528	.73	M	8.65**	1.85	2.37
S X Y X P	50	6.6388	.13	M	1.58*	1.39	1.59
S X Y X A	20	.0083	.00	M	<1	1.60	1.93
S X Y X P X A	100	.0035	.00	M	<1	1.26	1.39
MONTHS W/I SEAS. M	324	27.1810	.08				

POLICY	AVG. MONTHLY VALUE, INCHES	STATISTICAL SIGNIFICANCE 2/
0. FOREST	0.05	A
1. DEEP-ROOTED GRASS	0.05	A
2. SHALLOW-ROOTED GRASS	0.07	A
3. ZONES 2 & 3* DEEP GRASS	0.06	A
4. ZONES 2 & 3* ERODED & REPLANTED	0.34	B
5. RECREATION	0.06	A

1/ * AND ** INDICATE MEANS DIFFER SIGNIFICANTLY AT THE 5 AND 1 PERCENT LEVELS, RESPECTIVELY.

2/ MEANS FOLLOWED BY THE SAME LETTER DO NOT DIFFER SIGNIFICANTLY AT THE 5 PERCENT LEVEL ACCORDING TO DUNCAN S MULTIPLE RANGE TEST.

TABLE 25. - ANALYSIS OF VARIANCE, SUBSURFACE RUNOFF, INCHES

ASSUMING ALL VARIATES FIXED EXCEPT SEASONS AND MONTHS

SOURCE OF VARIATION	DEGREES OF FREEDOM	SUMS OF SQUARES	MEAN SQUARE	DENOM. FOR F-TEST	F 1/	F05	F01
GRAND TOTAL	648	2659.0682					
CORRECTION FOR MEAN	1	741.2961					
TOTAL CORRECTED	647	1917.7721					
POLICIES P	5	9.7153	1.94	SXP	3.11*	2.60	3.86
0512 VS. 34	1		1.69	SXP	2.70	4.24	7.77
05 VS. 12	1		6.75	SXP	10.80**	4.24	7.77
0 VS. 5	1		.48	SXP	<1	4.24	7.77
1 VS. 2	1		.60	SXP	<1	4.24	7.77
3 VS. 4	1		.20	SXP	<1	4.24	7.77
ANTECEDENT COND. A	2	.1096	.05	SXA	<1	4.10	7.56
P X A	10	.0050	.00	SXPXA	<1	2.02	2.70
TREATMENT YEARS Y	2	162.4031	81.20	SXY	1.78	4.10	7.56
Y X P	10	1.6420	.16	SXYXP	<1	2.02	2.70
Y X A	4	.0036	.00	SXYXA	<1	2.87	4.43
Y X P X A	20	.0010	.00	SXYXPXA	<1	1.68	2.06
SEASONS S	5	775.9821	155.20	M	103.88**	2.23	3.06
GROW. VS. DORM.	1		405.40	M	271.36**	3.86	6.70
WITHIN GROWING	2		11.52	M	7.71**	3.02	4.66
WITHIN DORMANT	2		173.77	M	116.32**	3.02	4.66
S X P	25	15.6290	.63	M	<1	1.54	1.84
S X A	10	.9347	.09	M	<1	1.85	2.37
S X P X A	50	.0643	.00	M	<1	1.39	1.59
S X Y	10	455.0996	45.51	M	30.46**	1.85	2.37
S X Y X P	50	12.0513	.24	M		1.39	1.59
S X Y X A	20	.0594	.00	M	<1	1.60	1.93
S X Y X P X A	100	.0369	.00	M	<1	1.26	1.39
MONTHS W/I SEAS. M	324	484.0352	1.49				

POLICY	AVG. MONTHLY VALUE, INCHES	STATISTICAL SIGNIFICANCE 2/
0. FOREST	0.86	A
1. DEEP-ROOTED GRASS	1.11	B C
2. SHALLOW-ROOTED GRASS	1.21	C
3. ZONES 2 & 3* DEEP GRASS	1.11	B C
4. ZONES 2 & 3* ERODED & REPLANTED	1.17	B C
5. RECREATION	0.96	A B

1/ * AND ** INDICATE MEANS DIFFER SIGNIFICANTLY AT THE 5 AND 1 PERCENT LEVELS, RESPECTIVELY.

2/ MEANS FOLLOWED BY THE SAME LETTER DO NOT DIFFER SIGNIFICANTLY AT THE 5 PERCENT LEVEL ACCORDING TO DUNCAN S MULTIPLE RANGE TEST.

TABLE 26. - ANALYSIS OF VARIANCE, EVAPOTRANSPIRATION EXCLUDING INTERCEPTION , INCHES

ASSUMING ALL VARIATES FIXED EXCEPT SEASONS AND MONTHS

SOURCE OF VARIATION	DEGREES OF FREEDOM	SUMS OF SQUARES	MEAN SQUARE	DENOM. FOR F-TEST	F 1/	F05	F01
GRAND TOTAL	648	3416.7540					
CORRECTION FOR MEAN	1	1863.9583					
TOTAL CORRECTED	647	1552.7957					
POLICIES P	5	17.6512	3.53	SXP	4.03**	2.60	3.86
0512 VS. 34	1		5.06	SXP	5.78*	4.24	7.77
05 VS. 12	1		.90	SXP	1.03	4.24	7.77
0 VS. 5	1		.31	SXP	<1	4.24	7.77
1 VS. 2	1		.91	SXP	1.04	4.24	7.77
3 VS. 4	1		10.47	SXP	11.95**	4.24	7.77
ANTECEDENT COND. A	2	.0144	.01	SXA	<1	4.10	7.56
P X A	10	.0774	.01	SXPXA	<1	2.02	2.70
TREATMENT YEARS Y	2	1.8963	.95	SXY	<1	4.10	7.56
Y X P	10	1.0800	.11	SXYXP	1.30	2.02	2.70
Y X A	4	.0528	.01	SXYXA	1.26	2.87	4.43
Y X P X A	20	.2158	.01	SXYXPXA	1.08	1.68	2.06
SEASONS S	5	1320.5967	264.12	M	530.03**	2.23	3.06
GROW. VS. DORM.	1		934.80	M	1875.96**	3.86	6.70
WITHIN GROWING	2		163.61	M	328.34**	3.02	4.66
WITHIN DORMANT	2		29.28	M	58.77**	3.02	4.66
S X P	25	21.9099	.88	M	1.76*	1.54	1.84
S X A	10	.0950	.01	M	<1	1.85	2.37
S X P X A	50	.4616	.01	M	<1	1.39	1.59
S X Y	10	21.9217	2.19	M	4.40**	1.85	2.37
S X Y X P	50	4.1652	.08	M	<1	1.39	1.59
S X Y X A	20	.2098	.01	M	<1	1.60	1.93
S X Y X P X A	100	.9968	.01	M	<1	1.26	1.39
MONTHS W/I SEAS. M	324	161.4510	.50				

POLICY	AVG. MONTHLY VALUE, INCHES	STATISTICAL SIGNIFICANCE 2/
0. FOREST	1.75	B
1. DEEP-ROOTED GRASS	1.87	B
2. SHALLOW-ROOTED GRASS	1.74	B
3. ZONES 2 & 3* DEEP GRASS	1.79	B
4. ZONES 2 & 3* ERODED & REPLANTED	1.35	A
5. RECREATION	1.68	B

1/ * AND ** INDICATE MEANS DIFFER SIGNIFICANTLY AT THE 5 AND 1 PERCENT LEVELS, RESPECTIVELY.

2/ MEANS FOLLOWED BY THE SAME LETTER DO NOT DIFFER SIGNIFICANTLY AT THE 5 PERCENT LEVEL ACCORDING TO DUNCAN S MULTIPLE RANGE TEST.

TABLE 27. - ANALYSIS OF VARIANCE, INTERCEPTION EVAPORATION, INCHES

ASSUMING ALL VARIATES FIXEO EXCEPT SEASONS ANO MONTHS

SOURCE OF VARIATION		DEGREES OF FREEDOM	SUMS OF SQUARES	MEAN SQUARE	DENOM. FOR F-TEST	F 1/	F05	F01
GRAND TOTAL		648	38.6250					
CORRECTION FOR MEAN		1	16.8522					
TOTAL CORRECTED		647	21.7728					
POLICIES P		5	14.6087	2.92	SXP	36.52**	2.60	3.86
0512 VS. 34	1			.38	SXP	4.78*	4.24	7.77
05 VS. 12	1			13.76	SXP	171.94**	4.24	7.77
0 VS. 5	1			.05	SXP	<1	4.24	7.77
1 VS. 2	1			.00	SXP	<1	4.24	7.77
3 VS. 4	1			.42	SXP	5.28*	4.24	7.77
ANTECEDENT CONO. A		2	.0001	.00	SXA	2.86	4.10	7.56
P X A		10	.0002	.00	SXPXA	<1	2.02	2.70
TREATMENT YEARS Y		2	.0126	.01	SXY	<1	4.10	7.56
Y X P		10	.0188	.00	SXYXP	<1	2.02	2.70
Y X A		4	.0002	.00	SXYXA	1.24	2.87	4.43
Y X P X A		20	.CC05	.00	SXYXPXA	1.08	1.68	2.06
SEASONS S		5	2.4211	.48	M	65.25**	2.23	3.06
GROW. VS. OORM.	1			.68	H	91.87**	3.86	6.70
WITHIN GROWING	2			.31	M	41.27**	3.02	4.66
WITHIN OORMANT	2			.56	M	75.90**	3.02	4.66
S X P		25	2.0002	.08	M	10.78**	1.54	1.84
S X A		10	.0002	.00	M	<1	1.85	2.37
S X P X A		50	.0009	.00	M	<1	1.39	1.59
S X Y		10	.1566	.02	M	2.11*	1.85	2.37
S X Y X P		50	.1448	.00	M	<1	1.39	1.59
S X Y X A		20	.0008	.00	M	<1	1.60	1.93
S X Y X P X A		100	.0025	.00	M	<1	1.26	1.39
MONTHS W/I SEAS. M		324	2.4046	.01				

POLICY	AVG. MONTHLY VALUE, INCHES	STATISTICAL SIGNIFICANCE 2/
0. FOREST	0.37	0
1. OEEP-ROOTEO GRASS	0.00	A
2. SHALLOW-ROOTEO GRASS	0.00	A
3. ZONES 2 & 3* OEEP GRASS	0.08	B
4. ZONES 2 & 3* EROOEO & REPLANTEO	0.17	C
5. RECREATION	0.34	0

1/ * ANO ** INOICATE MEANS OIFFER SIGNIFICANTLY AT THE 5 ANO I PERCENT LEVELS, RESPECTIVELY.

2/ MEANS FOLLOWEO BY THE SAME LETTER OO NOT OIFFER SIGNIFICANTLY AT THE 5 PERCENT LEVEL ACCOROING TO OUNCAN S MULTIPLE RANGE TEST.

TABLE 28. - ANALYSIS OF VARIANCE, EVAPOTRANSPIRATION INCLUDING INTERCEPTION , INCHES

ASSUMING ALL VARIATES FIXEO EXCEPT SEASONS ANO MONTHS

SOURCE OF VARIATION		DEGREES OF FREEDOM	SUMS OF SQUARES	MEAN SQUARE	DENOM. FOR F-TEST	F 1/	F05	F01
GRANO TOTAL		648	3910.9953					
CORRECTION FOR MEAN		1	2250.4222					
TOTAL CORRECTEO		647	1660.5731					
POLICIES P		5	23.5834	4.72	SXP	5.87**	2.60	3.86
0512 VS. 34	1			8.56	SXP	10.66**	4.24	7.77
05 VS. 12	1			7.08	SXP	8.81**	4.24	7.77
0 VS. 5	1			.59	SXP	<1	4.24	7.77
1 VS. 2	1			.66	SXP	<1	4.24	7.77
3 VS. 4	1			6.69	SXP	8.33**	4.24	7.77
ANTECEDENT CONO. A		2	.0034	.00	SXA	<1	4.10	7.56
P X A		10	.0151	.00	SXPXA	<1	2.02	2.70
TREATMENT YEARS Y		2	1.5381	.77	SXY	<1	4.10	7.56
Y X P		10	1.1067	.11	SXYXP	1.63	2.02	2.70
Y X A		4	.0131	.00	SXYXA	<1	2.87	4.43
Y X P X A		20	.0932	.00	SXYXPXA	1.40	1.68	2.06
SEASONS S		5	1411.0068	282.20	M	523.81**	2.23	3.06
GROW. VS. CORM.	1			986.00	M	1830.18**	3.86	6.70
WITHIN GROWING	2			175.04	M	324.91**	3.02	4.66
WITHIN OORMANT	2			37.46	M	69.53**	3.02	4.66
S X P		25	20.C838	.8C	M	1.49	1.54	1.84
S X A		10	.0348	.00	M	<1	1.85	2.37
S X P X A		50	.1801	.00	M	<1	1.39	1.59
S X Y		10	24.5589	2.46	M	4.56**	1.85	2.37
S X Y X P		50	3.3899	.07	M	<1	1.39	1.59
S X Y X A		20	.0799	.00	M	<1	1.60	1.93
S X Y X P X A		100	.3329	.00	M	<1	1.26	1.39
MONTHS W/I SEAS. M		324	174.5530	.54				

POLICY	AVG. MONTHLY VALUE, INCHES	STATISTICAL SIGNIFICANCE 2/
0. FOREST	2.13	C
1. OEEP-ROOTEO GRASS	1.87	B C
2. SHALLOW-ROOTEO GRASS	1.76	A B
3. ZONES 2 & 3* OEEP GRASS	1.88	B C
4. ZONES 2 & 3* EROOED & REPLANTEO	1.52	A
5. RECREATION	2.02	B C

1/ * ANO ** INOICATE MEANS OIFFER SIGNIFICANTLY AT THE 5 ANO 1 PERCENT LEVELS, RESPECTIVELY.

2/ MEANS FOLLOWEO BY THE SAME LETTER OO NOT OIFFER SIGNIFICANTLY AT THE 5 PERCENT LEVEL ACCOROING TO OUNCAN S MULTIPLE RANGE TEST.

Appendix D
Tables of Results

TABLE 29.--MONTHLY VALUES IN INCHES, WET ANTECEDENT AND WET POST-TREATMENT CONDITIONS, POLICY 0 MIXEO HARDWOOD AND PINE FOREST

MONTH	RAIN	ET	EI	EP	TOTAL RUNOFF	SUB-SURFACE RUNOFF
5	4.04	2.31	0.47	0.C0	2.17	1.69
6	1.99	4.92	C.59	0.C0	0.03	0.03
7	6.92	4.64	0.79	0.00	0.00	0.00
8	2.35	3.27	0.34	0.00	0.00	0.00
9	5.47	2.89	0.49	C.00	0.16	0.14
10	1.44	1.21	0.21	0.C0	0.00	0.00
11	5.91	0.25	0.24	0.00	1.38	1.31
12	2.31	0.19	0.08	0.02	1.22	1.22
1	4.22	0.24	0.27	0.03	5.41	5.33
2	3.09	0.23	0.26	0.05	3.62	2.92
3	4.54	0.56	0.38	0.00	3.39	3.39
4	2.99	0.85	0.57	0.C0	1.93	1.93

TABLE 30.--MONTHLY VALUES IN INCHES, WET ANTECEDENT AND AVERAGE POST-TREATMENT CONDITIONS, POLICY 0, MIXEO HARDWOOD AND PINE FOREST

MONTH	RAIN	ET	EI	EP	TOTAL RUNOFF	SUB-SURFACE RUNOFF
5	2.27	3.08	0.44	0.00	0.77	0.77
6	3.56	5.14	0.52	0.00	0.00	0.00
7	2.43	4.03	0.38	0.00	0.00	0.00
8	4.67	2.88	0.58	0.00	0.00	0.00
9	2.06	2.36	0.33	0.00	0.00	0.00
10	1.64	0.98	0.15	0.00	0.00	0.00
11	1.09	0.22	0.30	0.00	0.00	0.00
12	2.67	0.17	0.13	0.00	0.00	0.00
1	1.10	0.17	0.13	0.00	0.00	0.00
2	2.33	0.33	0.24	0.C0	0.01	0.01
3	7.97	0.96	0.63	0.C1	7.17	6.82
4	4.29	1.41	0.51	0.00	2.18	2.08

TABLE 31.--MONTHLY VALUES IN INCHES, WET ANTECEDENT AND DRY POST-TREATMENT CONDITIONS, POLICY 0, MIXED HARDWOOD AND PINE FOREST

MONTH	RAIN	ET	EI	EP	TOTAL RUNOFF	SUB-SURFACE RUNOFF
5	4.06	2.69	0.65	0.00	2.24	2.14
6	2.18	4.88	0.43	0.00	0.00	0.00
7	5.48	3.97	0.67	0.00	0.00	0.00
8	1.53	3.66	0.28	0.00	0.00	0.00
9	1.04	1.46	0.35	0.00	0.00	0.00
10	0.61	0.54	0.26	0.00	0.00	0.00
11	0.86	0.15	0.16	0.00	0.00	0.00
12	2.10	0.12	0.25	0.00	0.00	0.00
1	2.31	0.09	0.16	0.00	0.00	0.00
2	1.79	0.28	0.28	0.00	0.00	0.00
3	3.15	0.60	0.35	0.00	0.89	0.89
4	2.91	1.52	0.57	0.00	0.94	0.94

TABLE 35.--MONTHLY VALUES IN INCHES, DRY ANTECEDENT AND WET POST-TREATMENT CONDITIONS, POLICY 0, MIXED HARDWOOD AND PINE FOREST

MONTH	RAIN	ET	EI	EP	TOTAL RUNOFF	SUB-SURFACE RUNOFF
5	4.04	2.25	0.46	0.00	1.78	1.41
6	1.99	4.92	0.49	0.00	0.02	0.02
7	6.92	4.64	0.79	0.00	0.00	0.00
8	2.35	3.27	0.34	0.00	0.00	0.00
9	5.47	2.89	0.49	0.00	0.16	0.14
10	1.44	1.21	0.21	0.00	0.00	0.00
11	5.91	0.25	0.24	0.00	1.38	1.31
12	2.31	0.19	0.08	0.02	1.22	1.22
1	4.22	0.24	0.27	0.03	5.41	5.33
2	3.09	0.21	0.26	0.05	3.61	2.91
3	4.54	0.56	0.38	0.00	3.40	3.40
4	2.99	0.70	0.54	0.00	1.98	1.98

TABLE 32.--MONTHLY VALUES IN INCHES, AVERAGE ANTECEDENT AND WET POST-TREATMENT CONDITIONS, POLICY 0, MIXED HARDWOOD AND PINE FOREST

MONTH	RAIN	ET	EI	EP	TOTAL RUNOFF	SUB-SURFACE RUNOFF
5	4.03	2.29	0.45	0.00	1.84	1.44
6	1.99	4.92	0.59	0.00	0.02	0.02
7	6.92	4.64	0.79	0.00	0.00	0.00
8	2.35	3.27	0.34	0.00	0.00	0.00
9	5.47	2.89	0.49	0.00	0.16	0.14
10	1.44	1.21	0.21	0.00	0.00	0.00
11	5.91	0.25	0.24	0.00	1.38	1.31
12	2.31	0.19	0.08	0.02	1.22	1.22
1	4.22	0.24	0.27	0.03	5.41	5.33
2	3.09	0.21	0.26	0.05	3.61	2.91
3	4.54	0.56	0.38	0.00	3.40	3.40
4	2.99	0.70	0.54	0.00	1.98	1.98

TABLE 36.--MONTHLY VALUES IN INCHES, DRY ANTECEDENT AND AVERAGE POST-TREATMENT CONDITIONS, POLICY 0, MIXED HARDWOOD AND PINE FOREST

MONTH	RAIN	ET	EI	EP	TOTAL RUNOFF	SUB-SURFACE RUNOFF
5	2.27	3.06	0.44	0.00	0.34	0.34
6	3.56	5.13	0.52	0.00	0.00	0.00
7	2.43	4.02	0.38	0.00	0.00	0.00
8	4.67	2.88	0.58	0.00	0.00	0.00
9	2.06	2.36	0.33	0.00	0.00	0.00
10	1.64	0.98	0.15	0.00	0.00	0.00
11	1.09	0.22	0.30	0.00	0.00	0.00
12	2.67	0.17	0.13	0.00	0.00	0.00
1	1.10	0.17	0.13	0.00	0.00	0.00
2	2.33	0.31	0.24	0.00	0.00	0.00
3	7.97	0.91	0.63	0.01	7.23	6.90
4	4.29	1.42	0.52	0.00	2.17	2.07

TABLE 33.--MONTHLY VALUES IN INCHES, AVERAGE ANTECEDENT AND AVERAGE POST-TREATMENT CONDITIONS, POLICY 0, MIXED HARDWOOD AND PINE FOREST

MONTH	RAIN	ET	EI	EP	TOTAL RUNOFF	SUB-SURFACE RUNOFF
5	2.27	3.08	0.44	0.00	0.40	0.39
6	3.56	5.14	0.52	0.00	0.00	0.00
7	2.43	4.03	0.38	0.00	0.00	0.00
8	4.67	2.88	0.58	0.00	0.00	0.00
9	2.06	2.36	0.33	0.00	0.00	0.00
10	1.64	0.98	0.15	0.00	0.00	0.00
11	1.09	0.22	0.30	0.00	0.00	0.00
12	2.67	0.17	0.13	0.00	0.00	0.00
1	1.10	0.17	0.13	0.00	0.00	0.00
2	2.33	0.31	0.24	0.00	0.00	0.00
3	7.97	0.91	0.63	0.01	7.23	6.90
4	4.29	1.42	0.52	0.01	2.17	2.07

TABLE 37.--MONTHLY VALUES IN INCHES, DRY ANTECEDENT AND DRY POST-TREATMENT CONDITIONS, POLICY 0, MIXED HARDWOOD AND PINE FOREST

MONTH	RAIN	ET	EI	EP	TOTAL RUNOFF	SUB-SURFACE RUNOFF
5	4.06	2.67	0.65	0.00	1.80	1.72
6	2.18	4.88	0.43	0.00	0.00	0.00
7	5.48	3.97	0.67	0.00	0.00	0.00
8	1.53	3.66	0.28	0.00	0.00	0.00
9	1.04	1.46	0.35	0.00	0.00	0.00
10	0.61	0.54	0.26	0.00	0.00	0.00
11	0.86	0.15	0.16	0.00	0.00	0.00
12	2.10	0.12	0.25	0.00	0.00	0.00
1	2.31	0.09	0.16	0.00	0.00	0.00
2	1.79	0.28	0.26	0.00	0.00	0.00
3	3.15	0.57	0.37	0.00	0.90	0.90
4	2.91	1.50	0.57	0.00	0.99	0.98

TABLE 34.--MONTHLY VALUES IN INCHES, AVERAGE ANTECEDENT AND DRY POST-TREATMENT CONDITIONS, POLICY 0, MIXED HARDWOOD AND PINE FOREST

MONTH	RAIN	ET	EI	EP	TOTAL RUNOFF	SUB-SURFACE RUNOFF
5	4.06	2.69	0.64	0.00	1.88	1.78
6	2.18	4.88	0.43	0.00	0.00	0.00
7	5.48	3.97	0.67	0.00	0.00	0.00
8	1.53	3.66	0.28	0.00	0.00	0.00
9	1.04	1.46	0.35	0.00	0.00	0.00
10	0.61	0.54	0.26	0.00	0.00	0.00
11	0.86	0.15	0.16	0.00	0.00	0.00
12	2.10	0.12	0.25	0.00	0.00	0.00
1	2.31	0.09	0.16	0.00	0.00	0.00
2	1.79	0.28	0.26	0.00	0.00	0.00
3	3.15	0.57	0.37	0.00	0.90	0.90
4	2.91	1.50	0.57	0.00	0.99	0.98

TABLE 38.--MONTHLY VALUES IN INCHES, WET ANTECEDENT AND WET POST-TREATMENT CONDITIONS, POLICY 1, DEEP-ROOTED GRASS

MONTH	RAIN	ET	EI	EP	TOTAL RUNOFF	SUB-SURFACE RUNOFF
5	4.04	2.10	0.00	0.00	1.75	1.57
6	1.99	4.17	0.00	0.00	0.04	0.04
7	6.92	4.75	0.00	0.00	0.00	0.00
8	2.35	3.47	0.00	0.00	0.00	0.00
9	5.47	2.10	0.00	0.00	2.14	1.28
10	1.44	1.23	0.00	0.00	0.13	0.13
11	0.91	0.31	0.00	0.00	3.10	3.00
12	2.31	0.06	0.00	0.02	1.35	1.35
1	4.22	0.17	0.00	0.03	5.89	5.82
2	3.09	0.17	0.00	0.05	3.90	3.16
3	4.54	0.51	0.00	0.00	3.83	3.83
4	2.99	1.45	0.00	0.00	2.09	2.09

TABLE 39.--MONTHLY VALUES IN INCHES, WET ANTECEDENT AND AVERAGE POST-TREATMENT CONDITIONS, POLICY 1, DEEP-ROOTED GRASS

MONTH	RAIN	ET	EI	EP	TOTAL RUNOFF	SUB-SURFACE RUNOFF
5	2.27	4.22	0.00	0.00	0.52	0.52
6	3.56	4.32	0.00	0.00	0.00	0.00
7	2.43	4.05	0.00	0.00	0.00	0.00
8	4.67	3.15	0.00	0.00	0.00	0.00
9	2.06	2.27	0.00	0.00	0.00	0.00
10	1.64	1.08	0.00	0.00	0.00	0.00
11	1.09	0.42	0.00	0.00	0.00	0.00
12	2.67	0.10	0.00	0.00	0.00	0.00
1	1.10	0.08	0.00	0.00	0.00	0.00
2	2.33	0.26	0.00	0.00	2.00	2.00
3	7.97	1.66	0.00	0.01	8.04	8.00
4	4.29	2.03	0.00	0.00	1.95	1.95

TABLE 40.--MONTHLY VALUES IN INCHES, WET ANTECEDENT AND DRY POST-TREATMENT CONDITIONS, POLICY 1, DEEP-ROOTED GRASS

MONTH	RAIN	ET	EI	EP	TOTAL RUNOFF	SUB-SURFACE RUNOFF
5	4.06	3.76	0.00	0.00	1.73	1.73
6	2.18	4.33	0.00	0.00	0.00	0.00
7	5.48	4.06	0.00	0.00	0.00	0.00
8	1.53	3.84	0.00	0.00	0.00	0.00
9	1.04	1.74	0.00	0.00	0.00	0.00
10	0.61	0.87	0.00	0.00	0.00	0.00
11	0.86	0.31	0.00	0.00	0.00	0.00
12	2.10	0.17	0.00	0.00	0.00	0.00
1	2.31	0.08	0.00	0.00	0.00	0.00
2	1.79	0.38	0.00	0.00	0.72	0.72
3	3.15	0.52	0.00	0.00	2.67	2.67
4	2.91	2.74	0.00	0.00	0.73	0.73

TABLE 41.--MONTHLY VALUES IN INCHES, AVERAGE ANTECEDENT AND WET POST-TREATMENT CONDITIONS, POLICY 1, DEEP-ROOTED GRASS

MONTH	RAIN	ET	EI	EP	TOTAL RUNOFF	SUB-SURFACE RUNOFF
5	4.03	3.03	0.00	0.00	1.38	1.29
6	1.99	4.17	0.00	0.00	0.03	0.03
7	6.92	4.75	0.00	0.00	0.00	0.00
8	2.35	3.47	0.00	0.00	0.00	0.00
9	5.47	2.10	0.00	0.00	2.14	1.28
10	1.44	1.23	0.00	0.00	0.13	0.13
11	5.91	0.31	0.00	0.00	3.10	3.00
12	2.31	0.06	0.00	0.02	1.35	1.35
1	4.22	0.17	0.00	0.03	5.89	5.82
2	3.09	0.15	0.00	0.05	3.89	3.15
3	4.54	0.50	0.00	0.00	3.84	3.84
4	2.99	1.37	0.00	0.00	2.15	2.15

TABLE 42.--MONTHLY VALUES IN INCHES, AVERAGE ANTECEDENT AND AVERAGE POST-TREATMENT CONDITIONS, POLICY 1, DEEP-ROOTED GRASS

MONTH	RAIN	ET	EI	EP	TOTAL RUNOFF	SUB-SURFACE RUNOFF
5	2.27	4.20	0.00	0.00	0.09	0.09
6	3.56	4.32	0.00	0.00	0.00	0.00
7	2.43	4.05	0.00	0.00	0.00	0.00
8	4.67	3.15	0.00	0.00	0.00	0.00
9	2.06	2.27	0.00	0.00	0.00	0.00
10	1.64	1.08	0.00	0.00	0.00	0.00
11	1.09	0.42	0.00	0.00	0.00	0.00
12	2.67	0.10	0.00	0.00	0.00	0.00
1	1.10	0.08	0.00	0.00	0.00	0.00
2	2.33	0.25	0.00	0.00	1.88	1.88
3	7.97	1.58	0.00	0.01	8.23	8.19
4	4.29	2.07	0.00	0.00	1.93	1.93

TABLE 43.--MONTHLY VALUES IN INCHES, AVERAGE ANTECEDENT AND DRY POST-TREATMENT CONDITIONS, POLICY 1, DEEP-ROOTED GRASS

MONTH	RAIN	ET	EI	EP	TOTAL RUNOFF	SUB-SURFACE RUNOFF
5	4.06	3.73	0.00	0.00	1.29	1.29
6	2.18	4.33	0.00	0.00	0.00	0.00
7	5.48	4.06	0.00	0.00	0.00	0.00
8	1.53	3.84	0.00	0.00	0.00	0.00
9	1.04	1.74	0.00	0.00	0.00	0.00
10	0.61	0.87	0.00	0.00	0.00	0.00
11	0.86	0.31	0.00	0.00	0.00	0.00
12	2.10	0.17	0.00	0.00	0.00	0.00
1	2.31	0.08	0.00	0.00	0.00	0.00
2	1.79	0.37	0.00	0.00	0.51	0.51
3	3.15	0.51	0.00	0.00	2.89	2.89
4	2.91	2.68	0.00	0.00	0.82	0.82

TABLE 44.--MONTHLY VALUES IN INCHES, DRY ANTECEDENT AND WET POST-TREATMENT CONDITIONS, POLICY 1, DEEP-ROOTED GRASS

MONTH	RAIN	ET	EI	EP	TOTAL RUNOFF	SUB-SURFACE RUNOFF
5	4.04	2.98	0.00	0.00	1.21	1.18
6	1.99	4.17	0.00	0.00	0.03	0.03
7	6.92	4.75	0.00	0.00	0.00	0.00
8	2.35	3.47	0.00	0.00	0.00	0.00
9	5.47	2.10	0.00	0.00	2.14	1.28
10	1.44	1.23	0.00	0.00	0.13	0.13
11	5.91	0.31	0.00	0.00	3.10	3.00
12	2.31	0.06	0.00	0.02	1.35	1.35
1	4.22	0.17	0.00	0.03	5.89	5.82
2	3.09	0.15	0.00	0.05	3.89	3.15
3	4.54	0.50	0.00	0.00	3.84	3.84
4	2.99	1.37	0.00	0.00	2.15	2.15

TABLE 45.--MONTHLY VALUES IN INCHES, DRY ANTECEDENT AND AVERAGE POST-TREATMENT CONDITIONS, POLICY 1, DEEP-ROOTED GRASS

MONTH	RAIN	ET	EI	EP	TOTAL RUNOFF	SUB-SURFACE RUNOFF
5	2.27	4.14	0.00	0.00	0.00	0.00
6	3.56	4.28	0.00	0.00	0.00	0.00
7	2.43	4.02	0.00	0.00	0.00	0.00
8	4.67	3.14	0.00	0.00	0.00	0.00
9	2.06	2.27	0.00	0.00	0.00	0.00
10	1.64	1.08	0.00	0.00	0.00	0.00
11	1.09	0.42	0.00	0.00	0.00	0.00
12	2.67	0.10	0.00	0.00	0.00	0.00
1	1.10	0.08	0.00	0.00	0.00	0.00
2	2.33	0.25	0.00	0.00	1.87	1.87
3	7.97	1.58	0.00	0.01	8.23	8.19
4	4.29	2.07	0.00	0.00	1.93	1.93

TABLE 46.--MONTHLY VALUES IN INCHES, DRY ANTECEDENT AND DRY POST-TREATMENT CONDITIONS, POLICY 1, DEEP-ROOTED GRASS

MONTH	RAIN	ET	EI	EP	TOTAL RUNOFF	SUB-SURFACE RUNOFF
5	4.06	3.71	0.00	0.00	1.07	1.06
6	2.18	4.33	0.00	0.00	0.00	0.00
7	5.48	4.06	0.00	0.00	0.00	0.00
8	1.53	3.84	0.00	0.00	0.00	0.00
9	1.04	1.74	0.00	0.00	0.00	0.00
10	0.61	0.87	0.00	0.00	0.00	0.00
11	0.86	0.31	0.00	0.00	0.00	0.00
12	2.10	0.17	0.00	0.00	0.00	0.00
1	2.31	0.08	0.00	0.00	0.00	0.00
2	1.79	0.37	0.00	0.00	0.51	0.51
3	3.15	0.51	0.00	0.00	2.89	2.89
4	2.91	2.68	0.00	0.00	0.88	0.88

TABLE 47.--MONTHLY VALUES IN INCHES, WET ANTECEDENT AND WET POST-TREATMENT CONDITIONS, POLICY 2, SHALLOW-ROOTED GRASS

MONTH	RAIN	ET	EI	EP	TOTAL RUNOFF	SUB-SURFACE RUNOFF
5	4.04	3.02	0.00	0.00	1.82	1.62
6	1.99	3.78	0.00	0.C0	0.04	0.04
7	6.92	4.56	0.00	0.C0	0.02	0.01
8	2.35	3.31	0.00	0.00	0.00	0.00
9	5.47	2.04	C.00	0.00	2.89	1.54
10	1.44	1.19	0.00	0.C0	0.20	0.20
11	5.91	0.31	0.00	0.00	3.12	3.01
12	2.31	0.06	0.00	0.02	1.35	1.35
1	4.22	0.17	0.00	0.C3	5.89	5.82
2	3.09	0.17	0.00	0.C5	3.90	3.16
3	4.54	0.51	0.00	0.00	3.83	3.83
4	2.99	1.44	0.00	0.00	2.09	2.09

TABLE 48.--MONTHLY VALUES IN INCHES, WET ANTECEDENT AND AVERAGE POST-TREATMENT CONDITIONS, POLICY 2, SHALLOW-ROOTED GRASS

MONTH	RAIN	ET	EI	EP	TOTAL RUNOFF	SUB-SURFACE RUNOFF
5	2.27	3.96	0.00	0.C0	0.53	0.53
6	3.56	3.72	0.00	0.C0	0.00	0.00
7	2.43	3.36	0.00	0.00	0.00	0.00
8	4.67	2.93	0.0C	0.00	0.00	0.00
9	2.06	2.44	0.00	0.00	0.00	0.00
10	1.64	1.20	0.00	0.C0	0.00	0.00
11	1.09	0.46	0.0C	0.00	0.00	0.00
12	2.67	0.10	0.0C	0.00	0.00	0.00
1	1.10	0.05	0.00	0.C0	0.00	0.00
2	2.33	0.23	0.00	0.01	3.45	3.45
3	7.97	1.64	0.00	0.01	8.07	8.03
4	4.29	2.00	0.00	0.00	1.99	1.99

TABLE 49.--MONTHLY VALUES IN INCHES, WET ANTECEDENT AND DRY POST-TREATMENT CONDITIONS, POLICY 2, SHALLOW-ROOTED GRASS

MONTH	RAIN	ET	EI	EP	TOTAL RUNOFF	SUB-SURFACE RUNOFF
5	4.06	3.67	0.00	0.00	1.77	1.77
6	2.18	3.56	0.00	0.00	0.00	0.00
7	5.48	3.91	0.00	0.00	0.00	0.00
8	1.53	3.67	0.00	0.00	0.00	0.00
9	1.04	1.36	0.00	0.00	0.00	0.00
10	0.61	0.67	0.00	0.00	0.00	0.00
11	0.86	0.25	0.0C	0.C0	0.00	0.00
12	2.10	0.17	0.00	0.00	0.00	0.00
1	2.31	0.09	0.00	0.00	0.45	0.45
2	1.79	0.39	0.00	0.00	1.96	1.96
3	3.15	0.52	0.0C	0.C0	2.72	2.72
4	2.91	2.70	0.00	0.00	0.76	0.76

TABLE 50.--MONTHLY VALUES IN INCHES, AVERAGE ANTECEDENT AND WET POST-TREATMENT CONDITIONS, POLICY 2, SHALLOW-ROOTED GRASS

MONTH	RAIN	ET	EI	EP	TOTAL RUNOFF	SUB-SURFACE RUNOFF
5	4.03	2.91	0.00	0.00	1.49	1.36
6	1.99	3.78	0.00	0.00	0.04	0.04
7	6.92	4.56	0.00	0.00	0.02	0.01
8	2.35	3.31	0.00	0.C0	0.00	0.00
9	5.47	2.04	0.00	0.00	2.89	1.54
10	1.44	1.19	0.00	0.00	0.20	0.20
11	5.91	0.31	0.00	0.00	3.12	3.01
12	2.31	0.06	0.00	0.02	1.35	1.35
1	4.22	0.17	0.00	0.03	5.89	5.22
2	3.09	0.18	0.00	0.05	3.89	3.15
3	4.54	0.50	0.00	0.00	3.84	3.84
4	2.99	1.36	0.00	0.00	2.15	2.15

TABLE 51.--MONTHLY VALUES IN INCHES, AVERAGE ANTECEDENT AND AVERAGE POST-TREATMENT CONDITIONS, POLICY 2, SHALLOW-ROOTED GRASS

MONTH	RAIN	ET	EI	EP	TOTAL RUNOFF	SUB-SURFACE RUNOFF
5	2.27	3.92	0.0C	0.00	0.11	0.11
6	3.56	3.72	0.00	0.00	0.00	0.00
7	2.43	3.36	0.00	0.C0	0.00	0.00
8	4.67	2.93	0.00	0.00	0.00	0.00
9	2.06	2.44	0.0C	0.00	0.00	0.00
10	1.65	1.29	0.0C	0.00	0.00	0.00
11	1.09	0.46	0.00	0.00	0.00	0.00
12	2.67	0.10	0.00	C.00	0.00	0.00
1	1.10	0.05	0.00	0.00	0.00	0.00
2	2.33	0.22	0.00	0.C1	3.33	3.33
3	7.97	1.57	0.00	0.01	8.26	8.22
4	4.29	2.04	0.00	0.C0	1.97	1.97

TABLE 52.--MONTHLY VALUES IN INCHES, AVERAGE ANTECEDENT AND DRY POST-TREATMENT CONDITIONS, POLICY 2, SHALLOW-ROOTED GRASS

MONTH	RAIN	ET	EI	EP	TOTAL RUNOFF	SUB-SURFACE RUNOFF
5	4.06	3.62	C.0C	0.00	1.34	1.34
6	2.18	3.56	0.00	0.C0	0.00	0.00
7	5.48	3.91	0.00	0.C0	0.00	0.00
8	1.53	3.67	0.00	0.00	0.00	0.00
9	1.04	1.36	0.00	0.00	0.00	0.00
10	0.61	0.67	0.00	0.C0	0.00	0.00
11	0.86	0.25	0.00	0.00	0.00	0.00
12	2.10	0.17	0.00	0.00	0.00	0.00
1	2.31	0.09	0.00	0.C0	0.45	0.45
2	1.79	0.39	0.00	0.C0	1.68	1.68
3	3.15	0.51	0.00	0.00	3.02	3.02
4	2.91	2.64	0.00	0.00	0.84	0.84

TABLE 53.--MONTHLY VALUES IN INCHES, DRY ANTECEDENT AND WET POST-TREATMENT CONDITIONS, POLICY 2, SHALLOW-ROOTED GRASS

MONTH	RAIN	ET	EI	EP	TOTAL RUNOFF	SUB-SURFACE RUNOFF
5	4.03	2.83	0.00	0.00	1.35	1.27
6	1.99	3.78	0.00	0.C0	0.03	0.03
7	6.92	4.56	0.00	0.00	0.02	0.01
8	2.35	3.31	0.0C	0.00	0.00	0.00
9	5.47	2.04	0.00	0.00	2.89	1.54
10	1.44	1.19	0.00	C.00	0.20	0.20
11	5.91	0.31	0.00	0.00	3.12	3.01
12	2.31	0.06	0.00	0.02	1.35	1.35
1	4.22	0.17	0.00	0.C3	5.89	5.82
2	3.09	0.15	0.00	0.C5	3.89	3.15
3	4.54	0.50	0.00	0.00	3.84	3.84
4	2.99	1.36	0.00	0.00	2.15	2.15

TABLE 54.--MONTHLY VALUES IN INCHES, DRY ANTECEDENT AND AVERAGE POST-TREATMENT CONDITIONS, POLICY 2, SHALLOW-ROOTED GRASS

MONTH	RAIN	ET	EI	EP	TOTAL RUNOFF	SUB-SURFACE RUNOFF
5	2.27	3.85	0.00	0.00	0.00	0.00
6	3.56	3.69	0.00	0.00	0.00	0.00
7	2.43	3.35	0.00	0.00	0.00	0.00
8	4.67	2.93	0.0C	0.00	0.00	0.00
9	2.06	2.44	0.00	0.00	0.00	0.00
10	1.64	1.20	0.00	0.00	0.00	0.00
11	1.09	0.46	0.00	0.C0	0.00	0.00
12	2.67	0.10	0.00	0.00	0.00	0.00
1	1.10	0.05	0.00	0.00	0.00	0.00
2	2.33	0.22	0.00	0.01	3.33	3.33
3	7.97	1.57	0.00	0.CI	8.26	8.22
4	4.29	2.04	0.00	0.C0	1.97	1.97

TABLE 55.--MONTHLY VALUES IN INCHES, DRY ANTECEDENT AND DRY POST-TREATMENT CONDITIONS, POLICY 2, SHALLOW-ROOTED GRASS

MONTH	RAIN	ET	EI	EP	TOTAL RUNOFF	SUB-SURFACE RUNOFF
5	4.06	3.59	0.00	0.00	1.16	1.16
6	2.18	3.56	0.00	0.00	0.00	0.00
7	5.48	3.91	0.00	0.00	0.00	0.00
8	1.53	3.67	0.00	0.00	0.00	0.00
9	1.04	1.36	0.00	0.00	0.00	0.00
10	0.61	0.67	0.00	0.00	0.00	0.00
11	0.86	0.25	0.00	0.00	0.00	0.00
12	2.10	0.17	0.00	0.00	0.00	0.00
1	2.21	0.09	0.00	0.00	0.45	0.45
2	1.79	0.39	0.00	0.00	1.68	1.68
3	3.15	0.51	0.00	0.00	3.02	3.02
4	2.91	2.64	0.00	0.00	0.84	0.84

TABLE 56.--MONTHLY VALUES IN INCHES, WET ANTECEDENT AND WET POST-TREATMENT CONDITIONS, POLICY 3, ZONES 2 AND 3 TO DEEP-ROOTED GRASS

MONTH	RAIN	ET	EI	EP	TOTAL RUNOFF	SUB-SURFACE RUNOFF
5	4.04	2.64	0.11	0.00	2.12	1.87
6	1.99	4.42	0.15	0.00	0.03	0.03
7	6.92	4.77	0.21	0.00	0.00	0.00
8	2.35	3.44	0.09	0.00	0.00	0.00
9	5.47	2.33	0.13	0.00	1.48	0.99
10	1.44	1.19	0.05	0.00	0.07	0.07
11	5.91	0.24	0.04	0.00	2.80	2.68
12	2.31	0.06	0.01	0.02	1.35	1.35
1	4.22	0.14	0.05	0.03	5.86	5.79
2	3.09	0.14	0.05	0.05	3.88	3.09
3	4.54	0.40	0.06	0.00	3.88	3.87
4	2.99	1.12	0.10	0.00	2.23	2.23

TABLE 57.--MONTHLY VALUES IN INCHES, WET ANTECEDENT AND AVERAGE POST-TREATMENT CONDITIONS, POLICY 3, ZONES 2 AND 3 TO DEEP-ROOTED GRASS

MONTH	RAIN	ET	EI	EP	TOTAL RUNOFF	SUB-SURFACE RUNOFF
5	2.27	3.60	0.09	0.00	0.80	0.80
6	3.56	4.64	0.14	0.00	0.00	0.00
7	2.43	4.13	0.10	0.00	0.00	0.00
8	4.67	3.10	0.16	0.00	0.00	0.00
9	2.06	2.31	0.09	0.00	0.00	0.00
10	1.64	1.00	0.04	0.00	0.00	0.00
11	1.09	0.33	0.05	0.00	0.00	0.00
12	2.67	0.08	0.02	0.00	0.00	0.00
1	1.10	0.07	0.02	0.00	0.00	0.00
2	2.33	0.21	0.04	0.00	1.53	1.53
3	7.97	1.29	0.10	0.01	8.22	8.00
4	4.29	1.60	0.09	0.00	2.33	2.25

TABLE 58.--MONTHLY VALUES IN INCHES, WET ANTECEDENT AND DRY POST-TREATMENT CONDITIONS, POLICY 3, ZONES 2 AND 3 TO DEEP-ROOTED GRASS

MONTH	RAIN	ET	EI	EP	TOTAL RUNOFF	SUB-SURFACE RUNOFF
5	4.06	3.16	0.14	0.00	2.16	2.11
6	2.18	4.55	0.12	0.00	0.00	0.00
7	5.48	4.08	0.18	0.00	0.00	0.00
8	1.53	3.82	0.07	0.00	0.00	0.00
9	1.04	1.68	0.10	0.00	0.00	0.00
10	0.61	0.76	0.07	0.00	0.00	0.00
11	0.86	0.24	0.03	0.00	0.00	0.00
12	2.10	0.13	0.05	0.00	0.00	0.00
1	2.31	0.06	0.03	0.00	0.00	0.00
2	1.79	0.30	0.05	0.00	0.50	0.50
3	3.15	0.42	0.06	0.00	2.45	2.45
4	2.91	2.14	0.10	0.00	1.12	1.11

TABLE 59.--MONTHLY VALUES IN INCHES, AVERAGE ANTECEDENT AND WET POST-TREATMENT CONDITIONS, POLICY 3, ZONES 2 AND 3 TO DEEP-ROOTED GRASS

MONTH	RAIN	ET	EI	EP	TOTAL RUNOFF	SUB-SURFACE RUNOFF
5	4.03	2.60	0.10	0.00	1.76	1.57
6	1.99	4.42	0.15	0.00	0.02	0.02
7	6.92	4.77	0.21	0.00	0.00	0.00
8	2.35	3.44	0.09	0.00	0.00	0.00
9	5.47	2.33	0.13	0.00	1.48	0.99
10	1.44	1.19	0.05	0.00	0.07	0.07
11	5.91	0.24	0.04	0.00	2.80	2.68
12	2.31	0.06	0.01	0.02	1.35	1.35
1	4.22	0.14	0.05	0.03	5.86	5.79
2	3.09	0.12	0.05	0.05	3.87	3.08
3	4.54	0.40	0.06	0.00	3.88	3.88
4	2.99	1.06	0.10	0.00	2.29	2.29

TABLE 60.--MONTHLY VALUES IN INCHES, AVERAGE ANTECEDENT AND AVERAGE POST-TREATMENT CONDITIONS, POLICY 3, ZONES 2 AND 3 TO DEEP-ROOTED GRASS

MONTH	RAIN	ET	EI	EP	TOTAL RUNOFF	SUB-SURFACE RUNOFF
5	2.27	3.59	0.09	0.00	0.38	0.37
6	3.56	4.64	0.14	0.00	0.00	0.00
7	2.43	4.13	0.10	0.00	0.00	0.00
8	4.67	3.10	0.16	0.00	0.00	0.00
9	2.06	2.31	0.09	0.00	0.00	0.00
10	1.64	1.00	0.04	0.00	0.00	0.00
11	1.09	0.33	0.05	0.00	0.00	0.00
12	2.67	0.08	0.02	0.00	0.00	0.00
1	1.10	0.07	0.02	0.00	0.00	0.00
2	2.33	0.20	0.04	0.00	1.42	1.42
3	7.97	1.22	0.10	0.01	8.38	8.16
4	4.29	1.63	0.09	0.00	2.31	2.24

TABLE 61.--MONTHLY VALUES IN INCHES, AVERAGE ANTECEDENT AND DRY POST-TREATMENT CONDITIONS, POLICY 3, ZONES 2 AND 3 TO DEEP-ROOTED GRASS

MONTH	RAIN	ET	EI	EP	TOTAL RUNOFF	SUB-SURFACE RUNOFF
5	4.06	3.15	0.13	0.00	1.73	1.69
6	2.18	4.55	0.12	0.00	0.00	0.00
7	5.48	4.08	0.18	0.00	0.00	0.00
8	1.53	3.82	0.07	0.00	0.00	0.00
9	1.04	1.68	0.10	0.00	0.00	0.00
10	0.61	0.76	0.07	0.00	0.00	0.00
11	0.86	0.24	0.03	0.00	0.00	0.00
12	2.10	0.13	0.05	0.00	0.00	0.00
1	2.31	0.06	0.03	0.00	0.00	0.00
2	1.79	0.29	0.05	0.00	0.39	0.39
3	3.15	0.42	0.06	0.00	2.57	2.57
4	2.91	2.09	0.09	0.00	1.19	1.18

TABLE 62.--MONTHLY VALUES IN INCHES, DRY ANTECEDENT AND WET POST-TREATMENT CONDITIONS, POLICY 3, ZONES 2 AND 3 TO DEEP-ROOTED GRASS

MONTH	RAIN	ET	EI	EP	TOTAL RUNOFF	SUB-SURFACE RUNOFF
5	4.04	3.54	0.11	0.00	1.66	1.50
6	1.99	4.42	0.15	0.00	0.02	0.02
7	6.92	4.77	0.21	0.00	0.00	0.00
8	2.35	3.44	0.09	0.00	0.00	0.00
9	5.47	2.33	0.13	0.00	1.48	0.99
10	1.44	1.19	0.05	0.00	0.07	0.07
11	5.91	0.24	0.04	0.00	2.80	2.68
12	2.31	0.06	0.01	0.02	1.35	1.35
1	4.22	0.14	0.05	0.03	5.86	5.79
2	3.09	0.12	0.05	0.05	3.87	3.08
3	4.54	0.40	0.06	0.00	3.88	3.88
4	2.99	1.06	0.10	0.00	2.29	2.29

TABLE 63.--MONTHLY VALUES IN INCHES, DRY ANTECEDENT AND AVERAGE POST-TREATMENT CONDITIONS, POLICY 3, ZONES 2 AND 3 TO DEEP-ROOTED GRASS

MONTH	RAIN	ET	EI	EP	TOTAL RUNOFF	SUB-SURFACE RUNOFF
5	2.27	3.53	0.09	0.00	0.34	0.34
6	3.56	4.61	0.14	0.00	0.00	0.00
7	2.43	4.11	0.10	0.00	0.00	0.00
8	4.67	3.09	0.16	0.00	0.00	0.00
9	2.06	2.30	0.09	0.00	0.00	0.00
10	1.64	1.00	0.04	0.00	0.00	0.00
11	1.09	0.33	0.05	0.00	0.00	0.00
12	2.67	0.08	0.02	0.00	0.00	0.00
1	1.10	0.07	0.02	0.00	0.00	0.00
2	2.33	0.20	0.04	0.00	1.41	1.41
3	7.97	1.22	0.10	0.01	8.38	8.16
4	4.29	1.63	0.09	0.01	2.31	2.24

TABLE 64.--MONTHLY VALUES IN INCHES, DRY ANTECEDENT AND DRY POST-TREATMENT CONDITIONS, POLICY 3, ZONES 2 AND 3 TO DEEP-ROOTED GRASS

MONTH	RAIN	ET	EI	EP	TOTAL RUNOFF	SUB-SURFACE RUNOFF
5	4.06	3.12	0.14	0.00	1.60	1.58
6	2.18	4.55	0.12	0.00	0.00	0.00
7	5.48	4.08	0.18	0.00	0.00	0.00
8	1.53	3.22	0.07	0.00	0.00	0.00
9	1.04	1.68	0.10	0.00	0.00	0.00
10	0.61	0.76	0.07	0.00	0.00	0.00
11	0.86	0.24	0.03	0.00	0.00	0.00
12	2.10	0.13	0.05	0.00	0.00	0.00
1	2.31	0.06	0.03	0.00	0.00	0.00
2	1.79	0.29	0.05	0.00	0.39	0.39
3	3.15	0.42	0.06	0.00	2.57	2.57
4	2.91	2.09	0.09	0.00	1.19	1.18

TABLE 65.--MONTHLY VALUES IN INCHES, WET ANTECEDENT AND WET POST-TREATMENT CONDITIONS, POLICY 4, ZONES 2 AND 3 ERODED AND PLANTED TO PINES

MONTH	RAIN	ET	EI	EP	TOTAL RUNOFF	SUB-SURFACE RUNOFF
5	4.04	1.57	0.24	0.00	2.82	1.65
6	1.99	3.36	0.26	0.00	0.17	0.17
7	6.92	3.61	0.36	0.00	1.71	0.74
8	2.35	2.56	0.15	0.00	0.40	0.19
9	5.47	1.73	0.22	0.00	3.09	0.31
10	1.44	0.83	0.08	0.00	0.01	0.01
11	5.91	0.22	0.11	0.00	2.83	2.00
12	2.31	0.12	0.04	0.02	1.29	1.26
1	4.22	0.21	0.12	0.03	5.66	5.59
2	3.09	0.17	0.10	0.05	3.78	2.95
3	4.54	0.41	0.18	0.00	3.77	3.59
4	2.99	0.70	0.26	0.00	2.24	2.24

TABLE 66.--MONTHLY VALUES IN INCHES, WET ANTECEDENT AND AVERAGE POST-TREATMENT CONDITIONS, POLICY 4, ZONES 2 AND 3 ERODED AND PLANTED TO PINES

MONTH	RAIN	ET	EI	EP	TOTAL RUNOFF	SUB-SURFACE RUNOFF
5	2.27	1.94	0.23	0.00	1.26	1.07
6	3.56	3.62	0.25	0.00	0.72	0.34
7	2.43	3.32	0.18	0.00	0.00	0.00
8	4.67	2.72	0.27	0.00	0.59	0.05
9	2.06	2.04	0.17	0.00	0.36	0.12
10	1.64	0.89	0.10	0.00	0.01	0.01
11	1.09	0.27	0.12	0.00	0.00	0.00
12	2.67	0.18	0.06	0.00	0.02	0.02
1	1.10	0.17	0.05	0.00	0.00	0.00
2	2.33	0.30	0.12	0.00	2.55	2.50
3	7.97	0.76	0.32	0.01	8.33	6.89
4	4.29	0.98	0.26	0.00	2.97	2.24

TABLE 67.--MONTHLY VALUES IN INCHES, WET ANTECEDENT AND DRY POST-TREATMENT CONDITIONS, POLICY 4, ZONES 2 AND 3 ERODED AND PLANTED TO PINES

MONTH	RAIN	ET	EI	EP	TOTAL RUNOFF	SUB-SURFACE RUNOFF
5	4.06	1.72	0.32	0.00	2.94	2.39
6	2.18	3.41	0.19	0.00	0.03	0.03
7	5.48	3.23	0.32	0.00	0.93	0.39
8	1.53	3.04	0.11	0.00	0.33	0.20
9	1.04	1.47	0.16	0.00	0.00	0.00
10	0.61	0.64	0.10	0.00	0.00	0.00
11	0.86	0.21	0.06	0.00	0.00	0.00
12	2.10	0.19	0.11	0.00	0.00	0.00
1	2.31	0.13	0.07	0.00	0.29	0.29
2	1.79	0.33	0.11	0.00	1.60	1.55
3	3.15	0.48	0.16	0.00	2.42	2.41
4	2.91	1.11	0.23	0.00	1.75	1.46

TABLE 68.--MONTHLY VALUES IN INCHES, AVERAGE ANTECEDENT AND WET POST-TREATMENT CONDITIONS, POLICY 4, ZONES 2 AND 3 ERODED AND PLANTED TO PINES

MONTH	RAIN	ET	EI	EP	TOTAL RUNOFF	SUB-SURFACE RUNOFF
5	4.03	1.57	0.23	0.00	2.53	1.38
6	1.99	3.36	0.26	0.00	0.16	0.16
7	6.92	3.61	0.36	0.00	1.71	0.74
8	2.35	2.56	0.15	0.00	0.40	0.19
9	5.47	1.73	0.22	0.00	3.09	0.31
10	1.44	0.83	0.08	0.00	0.01	0.01
11	5.91	0.22	0.11	0.00	2.83	2.00
12	2.31	0.12	0.04	0.02	1.29	1.26
1	4.22	0.21	0.12	0.03	5.66	5.59
2	3.09	0.15	0.10	0.05	3.77	2.94
3	4.54	0.41	0.18	0.00	3.77	3.59
4	2.99	0.68	0.24	0.00	2.30	2.30

TABLE 69.--MONTHLY VALUES IN INCHES, AVERAGE ANTECEDENT AND AVERAGE POST-TREATMENT CONDITIONS, POLICY 4, ZONES 2 AND 3 ERODED AND PLANTED TO PINES

MONTH	RAIN	ET	EI	EP	TOTAL RUNOFF	SUB-SURFACE RUNOFF
5	2.27	1.95	0.26	0.00	0.96	0.78
6	3.56	3.62	0.25	0.00	0.78	0.34
7	2.43	3.32	0.18	0.00	0.00	0.00
8	4.67	2.72	0.27	0.00	0.59	0.05
9	2.06	2.04	0.17	0.00	0.36	0.12
10	1.64	0.89	0.10	0.00	0.01	0.01
11	1.09	0.27	0.12	0.00	0.00	0.00
12	2.67	0.18	0.06	0.00	0.02	0.02
1	1.10	0.17	0.05	0.00	0.00	0.00
2	2.33	0.29	0.11	0.00	2.45	2.39
3	7.97	0.73	0.32	0.01	8.47	7.04
4	4.29	0.98	0.26	0.00	2.97	2.23

TABLE 70.--MONTHLY VALUES IN INCHES, AVERAGE ANTECEDENT AND DRY POST-TREATMENT CONDITIONS, POLICY 4, ZONES 2 AND 3 ERODED AND PLANTED TO PINES

MONTH	RAIN	ET	EI	EP	TOTAL RUNOFF	SUB-SURFACE RUNOFF
5	4.06	1.73	0.31	0.00	2.63	2.09
6	2.18	3.41	0.19	0.00	0.03	0.03
7	5.48	3.33	0.32	0.00	0.93	0.39
8	1.53	3.04	0.11	0.00	0.33	0.20
9	1.04	1.47	0.16	0.00	0.00	0.00
10	0.61	0.64	0.10	0.00	0.00	0.00
11	0.86	0.21	0.06	0.00	0.00	0.00
12	2.10	0.19	0.11	0.00	0.00	0.00
1	2.31	0.13	0.07	0.00	0.29	0.29
2	1.79	0.32	0.10	0.00	1.36	1.30
3	3.15	0.48	0.16	0.00	2.67	2.67
4	2.91	1.09	0.23	0.00	1.77	1.49

TABLE 71.--MONTHLY VALUES IN INCHES, DRY ANTECEDENT AND WET POST-TREATMENT CONDITIONS, POLICY 4, ZONES 2 AND 3 ERODED AND PLANTED TO PINES

MONTH	RAIN	ET	EI	EP	TOTAL RUNOFF	SUB-SURFACE RUNOFF
5	4.04	1.55	0.23	0.00	2.56	1.41
6	1.99	3.36	0.26	0.00	0.16	0.16
7	6.92	3.61	0.36	0.00	1.71	0.74
8	2.35	2.56	0.15	0.00	0.40	0.19
9	5.47	1.73	0.22	0.00	3.09	0.31
10	1.44	0.83	0.08	0.00	0.01	0.01
11	5.91	0.22	0.11	0.00	2.83	2.00
12	2.31	0.12	0.04	0.02	1.29	1.26
1	4.22	0.21	0.12	0.03	5.66	5.59
2	3.09	0.15	0.10	0.05	3.77	2.94
3	4.54	0.41	0.18	0.00	3.77	3.59
4	2.99	0.68	0.24	0.00	2.30	2.30

TABLE 72.--MONTHLY VALUES IN INCHES, DRY ANTECEDENT AND AVERAGE POST-TREATMENT CONDITIONS, POLICY 4, ZONES 2 AND 3 ERODED AND PLANTED TO PINES

MONTH	RAIN	ET	EI	EP	TOTAL RUNOFF	SUB-SURFACE RUNOFF
5	2.27	1.94	0.23	0.00	0.99	0.80
6	3.56	3.62	0.25	0.00	0.72	0.34
7	2.43	3.32	0.18	0.00	0.00	0.00
8	4.67	2.72	0.27	0.00	0.59	0.05
9	2.06	2.04	0.17	0.00	0.36	0.12
10	1.64	0.89	0.10	0.00	0.01	0.01
11	1.09	0.27	0.12	0.00	0.00	0.00
12	2.67	0.18	0.06	0.00	0.02	0.02
1	1.10	0.17	0.05	0.00	0.00	0.00
2	2.33	0.29	0.11	0.00	2.45	2.39
3	7.97	0.73	0.32	0.01	8.47	7.04
4	4.29	0.98	0.26	0.00	2.97	2.23

TABLE 73.--MONTHLY VALUES IN INCHES, DRY ANTECEDENT AND DRY POST-TREATMENT CONDITIONS, POLICY 4, ZONES 2 AND 3 ERODED AND PLANTED TO PINES

MONTH	RAIN	ET	EI	EP	TOTAL RUNOFF	SUB-SURFACE RUNOFF
5	4.06	1.72	0.31	0.00	2.67	2.12
6	2.18	3.41	0.19	0.00	0.03	0.03
7	5.48	3.33	0.32	0.00	0.93	0.39
8	1.53	3.04	0.11	0.00	0.33	0.20
9	1.04	1.47	0.16	0.00	0.00	0.00
10	0.61	0.64	0.10	0.00	0.00	0.00
11	0.86	0.21	0.06	0.00	0.00	0.00
12	2.10	0.19	0.11	0.00	0.00	0.00
1	2.31	0.13	0.07	0.00	0.29	0.29
2	1.79	0.32	0.10	0.00	1.36	1.30
3	3.15	0.48	0.16	0.00	2.67	2.67
4	2.91	1.09	0.23	0.00	1.77	1.49

TABLE 74.--MONTHLY VALUES IN INCHES, WET ANTECEDENT AND WET POST-TREATMENT CONDITIONS, POLICY 5, RECREATIONAL USE

MONTH	RAIN	ET	EI	EP	TOTAL RUNOFF	SUB-SURFACE RUNOFF
5	4.04	2.07	0.43	0.00	2.38	1.85
6	1.99	4.65	0.54	0.00	0.03	0.03
7	6.92	4.54	0.73	0.00	0.00	0.00
8	2.35	3.28	0.32	0.00	0.00	0.00
9	5.47	2.72	0.45	0.00	0.42	0.25
10	1.44	1.17	0.19	0.00	0.00	0.00
11	5.91	0.22	0.22	0.00	2.00	1.89
12	2.31	0.16	0.08	0.02	1.24	1.24
1	4.22	0.19	0.25	0.03	5.50	5.42
2	3.09	0.19	0.24	0.05	3.67	2.93
3	4.54	0.49	0.34	0.00	3.51	3.51
4	2.99	0.70	0.52	0.00	2.05	2.05

TABLE 75.--MONTHLY VALUES IN INCHES, WET ANTECEDENT AND AVERAGE POST-TREATMENT CONDITIONS, POLICY 5, RECREATIONAL USE

MONTH	RAIN	ET	EI	EP	TOTAL RUNOFF	SUB-SURFACE RUNOFF
5	2.27	2.76	0.40	0.00	0.85	0.85
6	3.56	4.97	0.48	0.00	0.00	0.00
7	2.43	4.04	0.35	0.00	0.00	0.00
8	4.67	2.91	0.53	0.00	0.00	0.00
9	2.06	2.37	0.31	0.00	0.00	0.00
10	1.64	0.97	0.14	0.00	0.00	0.00
11	1.09	0.21	0.27	0.00	0.00	0.00
12	2.67	0.16	0.12	0.00	0.00	0.00
1	1.10	0.17	0.13	0.00	0.00	0.00
2	2.33	0.32	0.22	0.00	0.26	0.26
3	7.97	0.83	0.57	0.01	7.67	7.31
4	4.29	1.24	0.46	0.00	2.44	2.33

TABLE 76.--MONTHLY VALUES IN INCHES, WET ANTECEDENT AND DRY POST-TREATMENT CONDITIONS, POLICY 5, RECREATIONAL USE

MONTH	RAIN	ET	EI	EP	TOTAL RUNOFF	SUB-SURFACE RUNOFF
5	4.06	2.35	0.59	0.00	2.51	2.40
6	2.18	4.65	0.40	0.00	0.00	0.00
7	5.48	3.90	0.62	0.00	0.00	0.00
8	1.53	3.68	0.25	0.00	0.00	0.00
9	1.04	1.52	0.33	0.00	0.00	0.00
10	0.61	0.57	0.24	0.00	0.00	0.00
11	0.86	0.15	0.15	0.00	0.00	0.00
12	2.10	0.11	0.23	0.00	0.00	0.00
1	2.31	0.09	0.15	0.00	0.00	0.00
2	1.79	0.27	0.26	0.00	0.03	0.03
3	3.15	0.54	0.31	0.00	1.33	1.33
4	2.91	1.32	0.52	0.00	1.35	1.35

TABLE 77.--MONTHLY VALUES IN INCHES, AVERAGE ANTECEDENT AND WET POST-TREATMENT CONDITIONS, POLICY 5, RECREATIONAL USE

MONTH	RAIN	ET	EI	EP	TOTAL RUNOFF	SUB-SURFACE RUNOFF
5	4.03	2.06	0.42	0.00	2.04	1.55
6	1.99	4.65	0.54	0.00	0.03	0.03
7	6.92	4.54	0.73	0.00	0.00	0.00
8	2.35	3.28	0.32	0.00	0.00	0.00
9	5.47	2.72	0.45	0.00	0.42	0.25
10	1.44	1.17	0.19	0.00	0.00	0.00
11	5.91	0.22	0.22	0.00	2.00	1.89
12	2.31	0.16	0.08	0.02	1.24	1.24
1	4.22	0.19	0.25	0.03	5.50	5.42
2	3.09	0.16	0.24	0.05	3.66	2.92
3	4.54	0.49	0.34	0.00	3.52	3.51
4	2.99	0.61	0.49	0.00	2.11	2.11

TABLE 78.--MONTHLY VALUES IN INCHES, AVERAGE ANTECEDENT AND AVERAGE POST-TREATMENT CONDITIONS, POLICY 5, RECREATIONAL USE

MONTH	RAIN	ET	EI	EP	TOTAL RUNOFF	SUB-SURFACE RUNOFF
5	2.27	2.77	0.40	0.00	0.50	0.50
6	3.56	4.97	0.48	0.00	0.00	0.00
7	2.43	4.04	0.35	0.00	0.00	0.00
8	4.67	2.91	0.53	0.00	0.00	0.00
9	2.06	2.37	0.31	0.00	0.00	0.00
10	1.64	0.97	0.14	0.00	0.00	0.00
11	1.09	0.21	0.27	0.00	0.00	0.00
12	2.67	0.16	0.12	0.00	0.00	0.00
1	1.10	0.17	0.13	0.00	0.00	0.00
2	2.33	0.30	0.21	0.00	0.21	0.21
3	7.97	0.79	0.57	0.01	7.77	7.41
4	4.29	1.24	0.47	0.00	2.44	2.32

TABLE 79.--MONTHLY VALUES IN INCHES, AVERAGE ANTECEDENT AND DRY POST-TREATMENT CONDITIONS, POLICY 5, RECREATIONAL USE

MONTH	RAIN	ET	EI	EP	TOTAL RUNOFF	SUB-SURFACE RUNOFF
5	4.06	2.35	0.59	0.00	2.17	2.06
6	2.18	4.65	0.40	0.00	0.00	0.00
7	5.48	3.90	0.62	0.00	0.00	0.00
8	1.53	3.68	0.25	0.00	0.00	0.00
9	1.04	1.52	0.33	0.00	0.00	0.00
10	0.61	0.57	0.24	0.00	0.00	0.00
11	0.86	0.15	0.15	0.00	0.00	0.00
12	2.10	0.11	0.23	0.00	0.00	0.00
1	2.31	0.09	0.15	0.00	0.00	0.00
2	1.79	0.27	0.24	0.00	0.01	0.01
3	3.15	0.52	0.34	0.00	1.37	1.36
4	2.91	1.29	0.51	0.00	1.39	1.38

TABLE 80.--MONTHLY VALUES IN INCHES, DRY ANTECEDENT AND WET POST-TREATMENT CONDITIONS, POLICY 5, RECREATIONAL USE

MONTH	RAIN	ET	EI	EP	TOTAL RUNOFF	SUB-SURFACE RUNOFF
5	4.04	2.03	0.43	0.00	2.01	1.52
6	1.99	4.65	0.54	0.00	0.03	0.03
7	6.92	4.54	0.73	0.00	0.00	0.00
8	2.35	3.28	0.32	0.00	0.00	0.00
9	5.47	2.72	0.45	0.00	0.42	0.25
10	1.44	1.17	0.19	0.00	0.00	0.00
11	5.91	0.22	0.22	0.00	2.00	1.89
12	2.31	0.16	0.08	0.02	1.24	1.24
1	4.22	0.19	0.25	0.03	5.50	5.42
2	3.09	0.16	0.24	0.05	3.66	2.92
3	4.54	0.49	0.34	0.00	3.52	3.51
4	2.99	0.61	0.49	0.00	2.11	2.11

TABLE 81.--MONTHLY VALUES IN INCHES, DRY ANTECEDENT AND AVERAGE POST-TREATMENT CONDITIONS, POLICY 5, RECREATIONAL USE

MONTH	RAIN	ET	EI	EP	TOTAL RUNOFF	SUB-SURFACE RUNOFF
5	2.27	2.75	0.40	0.00	0.44	0.44
6	3.56	4.97	0.48	0.00	0.00	0.00
7	2.43	4.04	0.35	0.00	0.00	0.00
8	4.67	2.91	0.53	0.00	0.00	0.00
9	2.06	2.37	0.31	0.00	0.00	0.00
10	1.64	0.97	0.14	0.00	0.00	0.00
11	1.09	0.21	0.27	0.00	0.00	0.00
12	2.67	0.16	0.12	0.00	0.00	0.00
1	1.10	0.17	0.13	0.00	0.00	0.00
2	2.33	0.30	0.21	0.00	0.21	0.21
3	7.97	0.79	0.57	0.01	7.77	7.41
4	4.29	1.24	0.47	0.00	2.44	2.32

TABLE 82.--MONTHLY VALUES IN INCHES, DRY ANTECEDENT AND DRY POST-TREATMENT CONDITIONS, POLICY 5, RECREATIONAL USE

MONTH	RAIN	ET	EI	EP	TOTAL RUNOFF	SUB-SURFACE RUNOFF
5	4.06	2.34	0.59	0.00	2.11	2.00
6	2.18	4.65	0.40	0.00	0.00	0.00
7	5.48	3.90	0.62	0.00	0.00	0.00
8	1.53	3.68	0.25	0.00	0.00	0.00
9	1.04	1.52	0.33	0.00	0.00	0.00
10	0.61	0.57	0.24	0.00	0.00	0.00
11	0.86	0.15	0.15	0.00	0.00	0.00
12	2.10	0.11	0.23	0.00	0.00	0.00
1	2.31	0.09	0.15	0.00	0.00	0.00
2	1.79	0.27	0.24	0.00	0.01	0.01
3	3.15	0.52	0.34	0.00	1.37	1.36
4	2.91	1.29	0.51	0.00	1.39	1.38

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